US 101 MP 354.01 Unnamed Tributary to Skookum Creek: Preliminary Hydraulic Design Report

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US 101 Unnamed Tributary to Skookum - Remove Fish Barrier
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Preliminary Hydraulic Design Report
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1.0 Introduction and Purpose

To comply with United States, et al vs. Washington, et al No. C70-9213 Subproceeding No. 01-1 dated March 29, 2013 (a federal permanent injunction requiring the State of Washington to correct fish barriers in Water Resource Inventory Areas (WRIAs) 1-23), the Washington State Department of Transportation (WSDOT) is proposing a project to provide fish passage at the US 101 crossing of Unnamed Tributary to Skookum Creek at Mile Post (MP) 354.01. This existing structure on US 101 has been identified as a fish barrier by Washington Department of Fish and Wildlife (WDFW) and WSDOT Environmental Services Office (ESO) (Site ID 997158) due to a water surface drop at the outlet. Per the injunction, and in order of preference, fish passage should be achieved by (a) avoiding the necessity for the roadway to cross the stream, (b) use of a full span bridge, or (c) use of the stream simulation methodology. WSDOT evaluated design options as defined in the injunction. Avoidance of the stream crossing was determined to not be viable given the location of the highway and the need to maintain this critical transportation corridor. WSDOT is proposing to replace the existing crossing structure with a structure designed using the stream simulation culvert design methodology.

The structure is located in Mason County 0.3 miles south of Kamilche, WA in Water Resource Inventory Area (WRIA) 14. The highway runs north-south at this location and is about 1,600 feet from the unnamed tributary’s confluence with Skookum Creek. The unnamed tributary generally flows southwest to northeast beginning in the forested sections of the Salish Cliffs Golf Club, is piped under a portion of the golf course through a 36-inch high-density polyethylene (HDPE) pipe, and outfalls into the stream channel approximately 200 feet upstream of its crossing with US 101 (Figure 1).

The proposed project will replace the existing 186.7 feet long, 36-inch diameter concrete culvert with a minimum 16 foot span structure to improve fish passage while providing a safe roadway for the traveling public. This proposed structure is designed to meet the requirements of the federal injunction utilizing the culvert design criteria outlined in the 2013 WDFW Water Crossing Design Guidelines (WCDG).

There have been ongoing discussion about potentially shortening the stream grading upstream of the crossing to keep the proposed stream grading within the WSDOT right-of-way. The potential grading revision was assessed and would increase the design slope to approximately 3.3% and would result in a slope ratio of 1.1. The PHD has not been updated to reflect this potential revision as a decision has not been finalized and the slope ratio is still anticipated to be below 1.25. Further discussion is provided in Section 8.2.5.

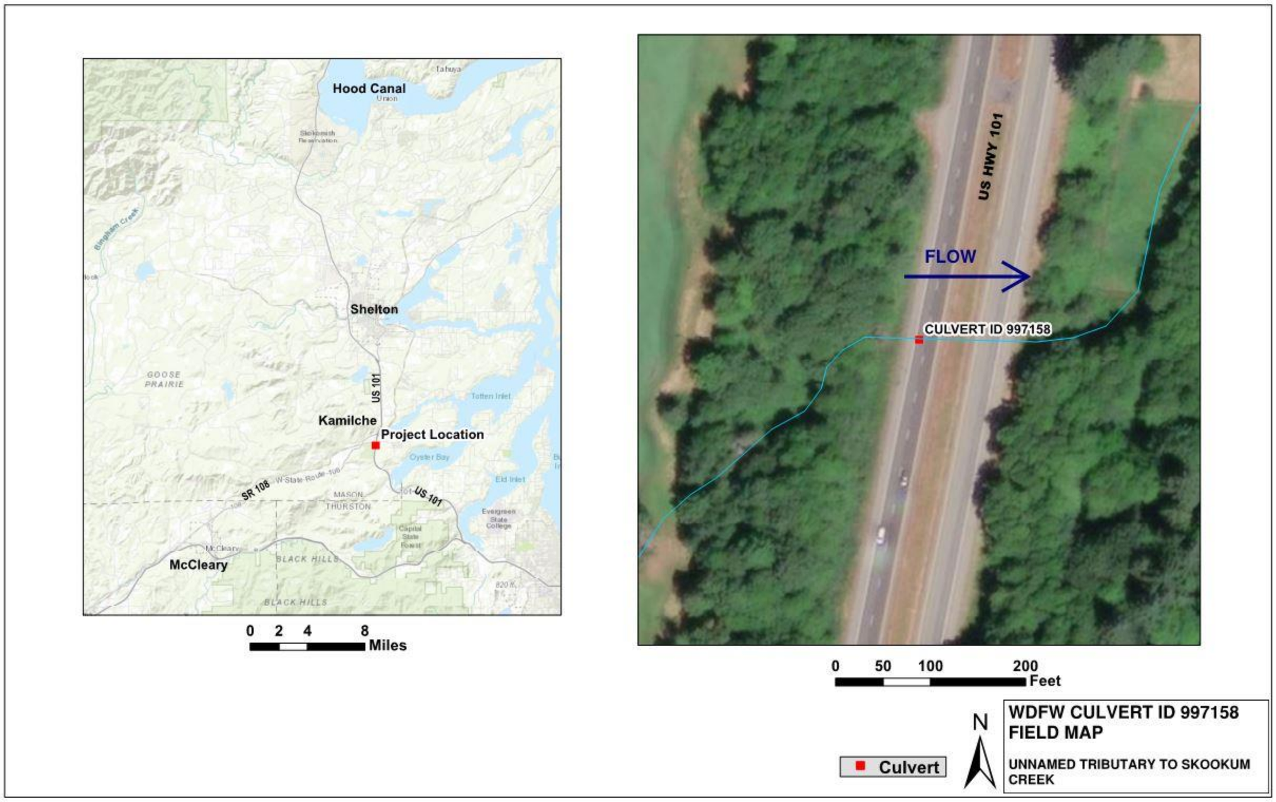


Figure 1 Vicinity map

2.0 Site Assessment

Osborn Consulting, Inc. (OCI) and HDR conducted a site visit on August 23, 2019 to visually assess the stream and collect information to support the design of the Unnamed Tributary to Skookum Creek. OCI also conducted an independent site visit on August 29, 2019 to supplement prior field efforts. The team walked the stream from approximately 200 feet upstream of the inlet to approximately 300 feet downstream of the outlet of the existing 36-inch diameter concrete culvert. The following provides a description of field observations moving from upstream to downstream.

The headwaters of the unnamed tributary flow through forested sections of the Salish Cliffs Golf Club golf course. The tributary is then piped beneath a portion of the golf course and outfalls from a 36-inch HDPE pipe into a scour pool (Figure 2). Downstream of the pool, the channel makes a sharp right turn and flows through a relatively straight reach for approximately 200 feet before reaching the existing US 101 culvert crossing. In the reach upstream of the US 101 culvert inlet, the stream corridor is densely vegetated, primarily with small trees, and shrubs. The reach appears to contain relatively few large trees which are scattered along the reach and appear to limit canopy cover. The channel is narrow and incised, with depth of incision varying from approximately 4 to 6-feet (Figure 3). Evidence of undercut banks is present throughout the reach.

Figure 2 36" HDPE pipe outlet from golf course (Left) and typical upstream riparian vegetation (Right)

Figure 3 Typical stream channel (Left) and typical bank erosion (Right) upstream of existing culvert

The channel incision has exposed a glacial till layer in the streambed along the reach between the golf course pipe outfall and the US 101 culvert. However, there are several sections of the channel (approximately one-third of the reach) where fine to coarse gravels are present (Figure 4). There is minimal wood accumulation throughout the stream channel, and moderate wood recruitment potential due to the limited number of trees along the reach upstream of the US 101 culvert.

Figure 4 Streambed showing glacial till layer with interspersed gravel

Two bankfull width measurements were taken approximately 80 feet and 50 feet upstream of the existing culvert inlet, which measured 5.8 feet and 6.5 feet respectively (Figure 5).

Figure 5 Bankfull width measurement locations 80 feet (Left) and 50 feet (Right) upstream of existing culvert

At the existing US 101 culvert inlet, the stream has deeply eroded into the left bank and roadway embankment behind the culvert. Downstream of the US 101 crossing, an approximate 2-foot water surface drop exists below the culvert outlet. A large scour hole has formed below the outlet that opens into a pool and appears to have deeply undercut banks. It appears riprap has been placed in the channel just downstream of the pool. See Figure 6 for photos of the US 101 culvert inlet and outlet.

Figure 6 Existing US 101 culvert inlet (Left) and outlet with scour pool (Right)

Downstream of the US 101 crossing, the channel flows through a corridor that is densely vegetated with grass, shrubs, blackberry, and large trees. Approximately 40 feet downstream of the culvert, the stream channel narrows and becomes moderately incised, with bank heights ranging from approximately 3 to 4 feet. The stream banks along the channel appear to be deeply undercut (Figure 7).

Figure 7 Typical downstream riparian vegetation (Left) and Undercut banks in downstream channel (Right)

In the downstream reach, the streambed appears to be composed primarily of fines, with sections that contain gravels and some small cobbles. One bankfull width measurement was taken approximately 40 feet downstream of the existing culvert outlet, which measured 8.2 feet (Figure 8).

Figure 8 Bankfull width measurement location downstream of existing culvert

A tributary enters the stream from the right bank approximately 100 feet downstream of the culvert outlet. Bankfull width measurements were not taken downstream of the confluence with the tributary as they would not be representative of the stream channel at the culvert. The channel widens just past the WSDOT right-of-way, and becomes less incised than the upstream reach, with bank heights ranging from approximately 2 to 3 feet. Relatively few wood accumulations were observed in the stream, however, large trees exist along the channel that have the potential to contribute to wood recruitment.

3.0 Watershed Assessment

3.1 Watershed & Landcover

The Unnamed Tributary to Skookum Creek flows in a generally northeasterly direction and joins Skookum Creek approximately 1,600 feet downstream of the existing US 101 crossing. Skookum Creek drains into the Little Skookum Inlet near Kamilche, which flows into Totten Inlet and eventually into the Puget Sound. The drainage area to the tributary at the existing US 101 culvert crossing is 0.24 square miles with an average mean annual precipitation of 64.1 inches (PRISM). The majority of the basin is comprised of the Salish Cliffs Golf Club, consisting mainly of grassed and landscaped golf course areas, pockets of forested areas, and a small amount of impervious land and water features. The land cover within the upper portion (approximately one third) of the basin consists of scrub/shrub land with pockets of forested tree canopy based on ESRI aerial imagery and 2016 NLCD land cover data. Figure 9 shows a map of the basin boundary.

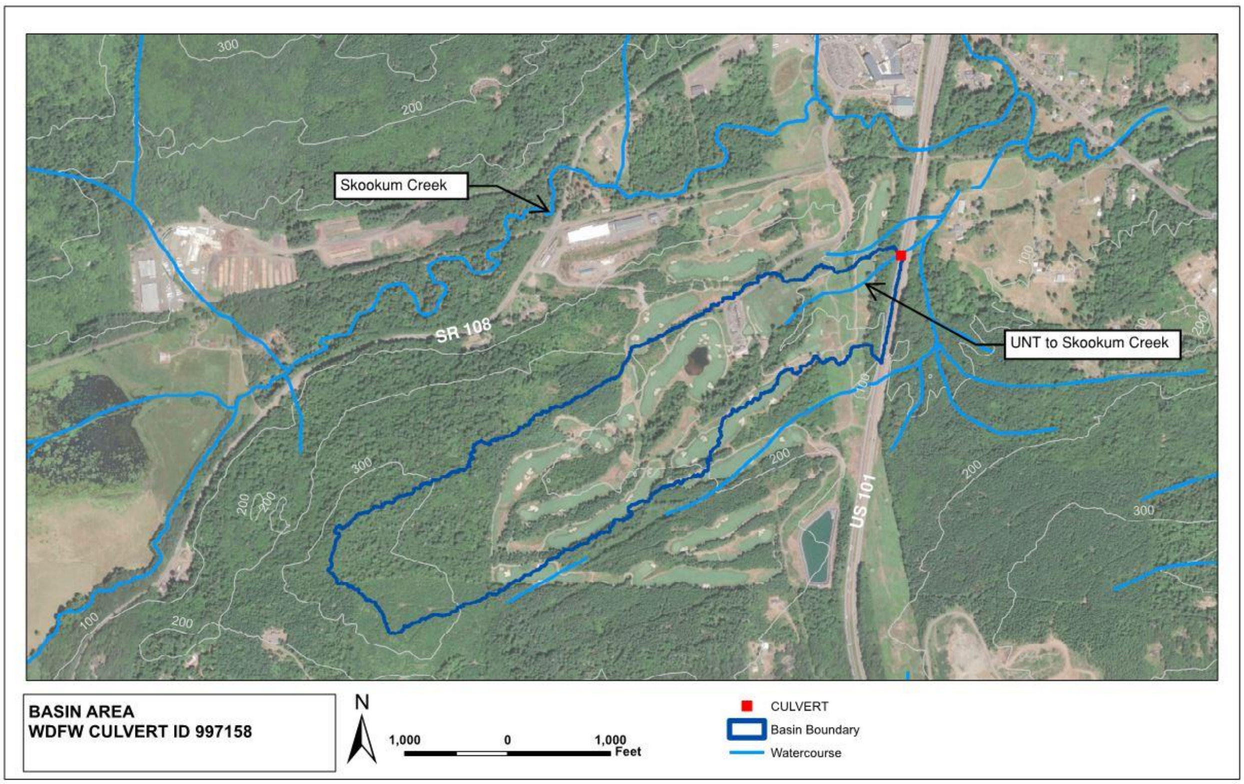


Figure 9 Basin boundary

3.2 Mapped Floodplains

The existing US 101 culvert is located in Zone X, an area of minimal flood hazard, based on FEMA Flood Insurance Rate Map (FIRM) 53045C0775E (Figure 10). The project site is located approximately 900 feet outside of the FEMA-mapped 100-Year floodplain of Skookum Creek.

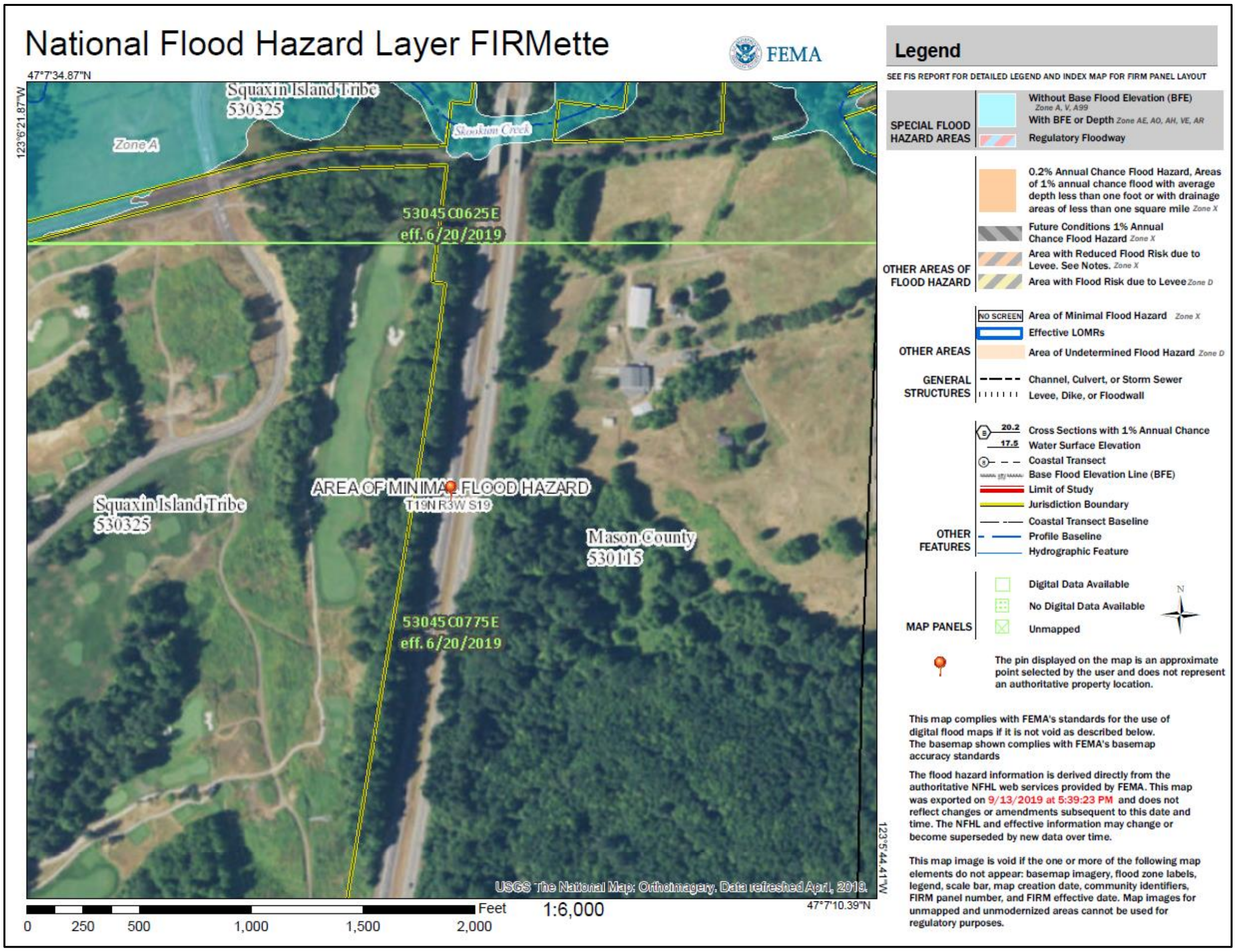


Figure 10 FEMA mapped floodplain (FIRM 53045C0775E)

3.3 Geology & Soils

The drainage basin to the Unnamed Tributary to Skookum Creek is primarily underlain by continental glacial deposits including Vashon Stade till and outwash. Continental glacial deposits typically contain granitic and metamorphic rock and abundant polycrystalline quartz (Logan, 2003). The majority of the basin consists of Vashon Stade till (Qgt). Limited areas of Vashon Stade proglacial and recessional outwash (Qgo) and non-glacial Kitsap Formation sedimentary deposits (Qc_k) are found at the downstream end of the basin near the Skookum Creek floodplain. Figure 11 shows a map of the geologic units in the drainage basin. These geologic units are further described as follows:

> **(Qc_k) Continental sedimentary deposits (Pleistocene epoch), Kitsap Formation** – Pleistocene nonglacial deposits; silt and fine sand with interbedded peat and organic layers; olive-brown where oxidized to blue-gray where fresh.
>
> **(Qgo) Proglacial and recessional outwash, late Wisconsinan (Pleistocene epoch), Vashon Stade** - Continental glacial deposits of Fraser Glaciation; poorly to moderately sorted, rounded gravel and sand with localized coarser- and finer-grained constituents; typically shades of gray where fresh or brown where stained

(Qgt) Till, late Wisconsinan (Pleistocene epoch), Vashon Stade – Continental glacial deposits of Fraser Glaciation; unsorted, unstratified, highly compacted mixture of clay, silt, sand, gravel, and boulders deposited by glacial ice; typically gray and may contain interbedded stratified sand, silt, and gravel

Elevations within the watershed range between approximately 50 feet to 370 feet above sea level based on USGS StreamStats. Based on contours (source: Mason County GIS), the majority of the watershed is mildly sloped at 2-15%, with some areas of slopes up to 30% or locally greater.

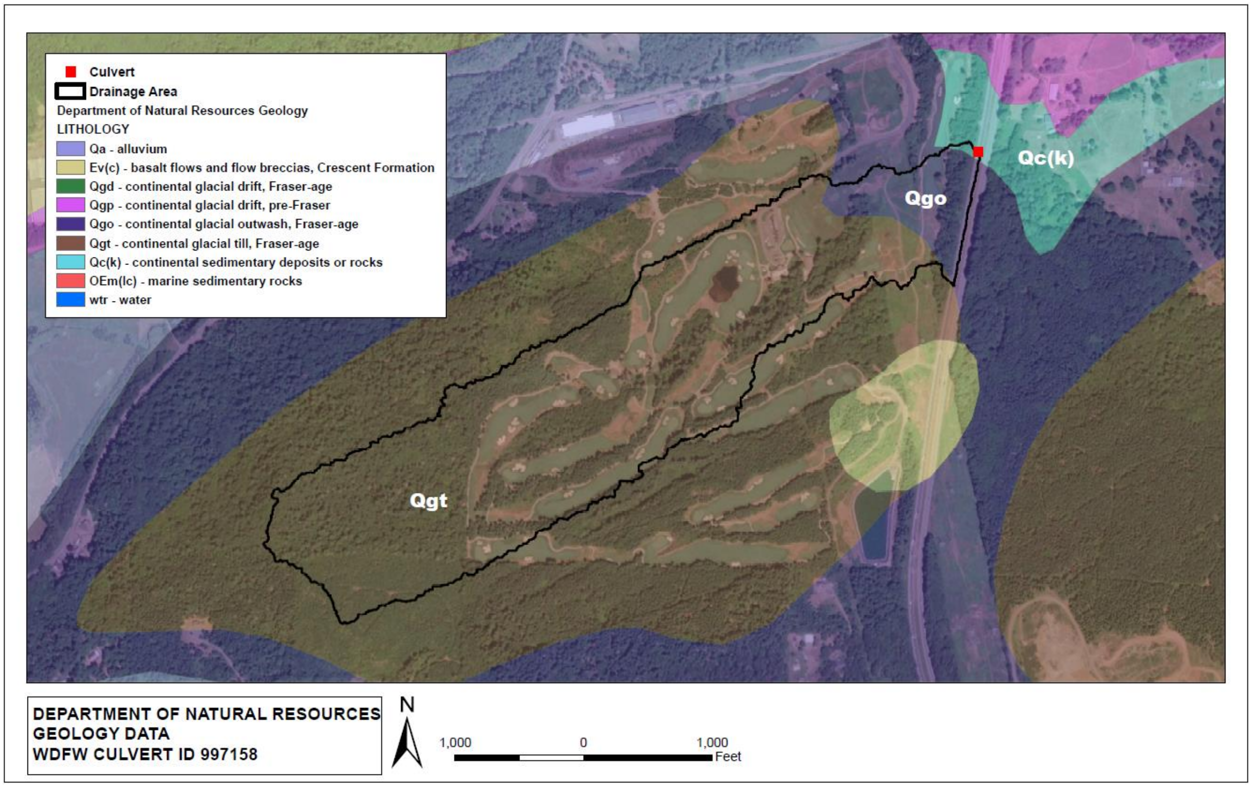
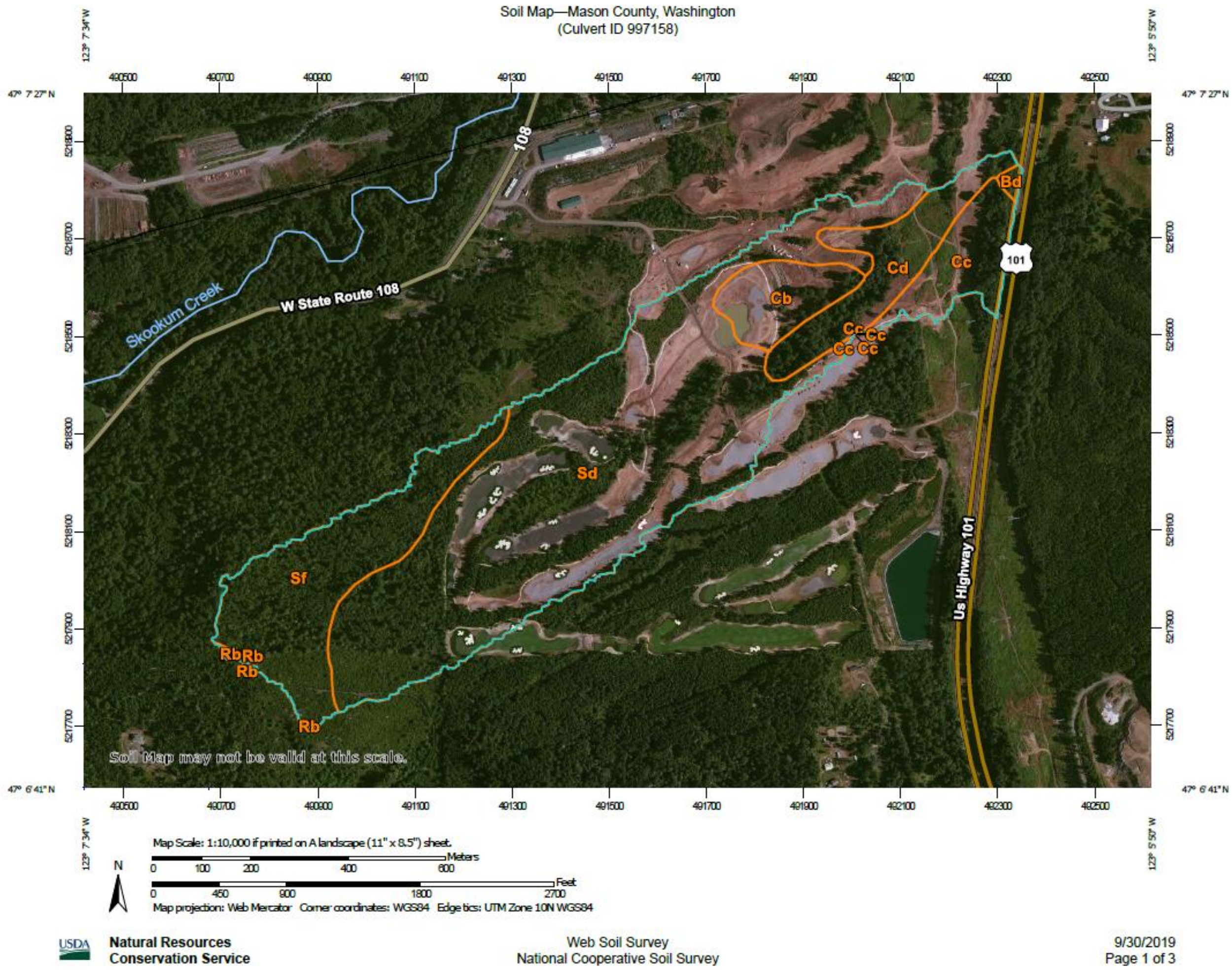


Figure 11 Surficial Geology (WA DNR Geologic Units 1:100,000 Scale)

Soils in the basin primarily include silt loam, gravelly loam, and gravelly sandy loam. The upper portion of the basin consists mainly of soils in hydrologic soil group (HSG) A (78%), and the lower basin consists mainly of HSG C soils (22%). HSG A soils are typically well-drained with high infiltration rate, and HSG C soils are typically fine textured with slow infiltration rate. The basin is primarily Shelton gravelly loam (Sd/Sf) while the soil map unit in the lower channel is Cloquallum silt loam. Figure 12 shows a map and table of the soil units in the basin.



Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
Bd	Bellingham silt loam, 0 to 3 percent slopes	0.5	0.4%
Cb	Cloquallum silt loam, 0 to 5 percent slopes	8.6	5.6%
Cc	Cloquallum silt loam, 5 to 15 percent slopes	9.8	6.4%
Cd	Cloquallum silt loam, 15 to 30 percent slopes	14.0	9.1%
Rb	Rough broken land	0.2	0.1%
Sd	Shelton gravelly loam, 5 to 15 percent slopes	93.5	60.9%
Sf	Shelton gravelly sandy loam, 5 to 15 percent slopes	26.8	17.5%
Totals for Area of Interest		**153.5**	**100.0%**

Figure 12 NRCS Web Soil Survey

3.4 Geomorphology

3.4.1 Channel Geometry

The channel in the upstream reach contains a large pool at the outlet of the HDPE pipe that crosses beneath the golf course. Downstream of the pool, the channel makes a sharp right turn, then flows through a relatively straight reach to the culvert inlet. The channel becomes incised, with depth of incision ranging from 4 to 6 feet and flows over hard glacial till (Figure 13). The channel appears to be entrenched; stream benches were not observed in the reach upstream of the culvert inlet. Upstream bankfull widths measured 5.8 feet and 6.5 feet. At the culvert inlet, erosion was observed on the left bank and into the roadway embankment behind the culvert.

In the downstream reach, a pool has formed below the culvert outlet that contains deeply undercut banks. The channel downstream of the pool becomes slightly incised, with bank heights ranging from 2 to 4 feet. The channel downstream of the US 101 crossing appeared to be wider than the upstream reach. One downstream bankfull width was taken that measured 8.2 feet (Figure 13).

Figure 13 Upstream channel showing incision (Left) and the wider downstream channel (Right)

Based on the basin area (0.24 square miles) and annual precipitation (64.1 inches per year), the WDFW regression equation estimates a bankfull width to be 6.3 feet.

A long channel profile was developed from the 2019 survey data and 2005 Puget Sound Lowlands LiDAR data (Figure 14). Upstream of the project area, the average reach slope is 2 percent. Within the detailed survey, the reach slope increases to an average of 3 percent. The reach downstream of the survey is less steep, with an average slope of 1 percent.

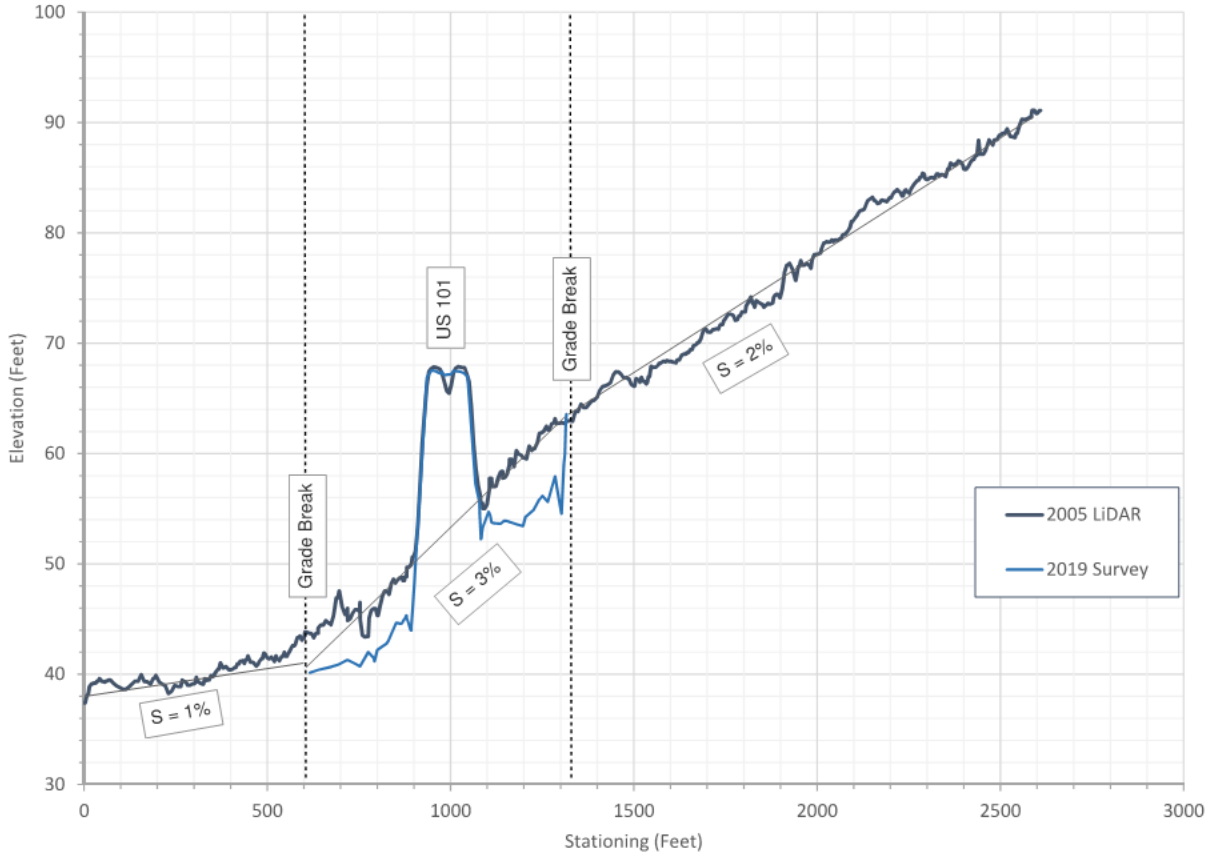


Figure 14 Long profile of UNT near the US 101 crossing

3.4.2 Potential for Aggradation, Incision and Headcutting

The headwaters of the Unnamed Tributary flow through forested sections of the Salish Cliffs Golf Club golf course which appear to have a relatively low gradient. The tributary is then piped beneath a portion of the golf course for what appears to be a significant length, and outfalls from a 36-inch HDPE pipe into a scour pool. The upstream channel is potentially influenced by the modified landscape of the golf course, in addition to the considerable length the stream is piped beneath the golf course may limit sediment supply to the downstream system. The channel upstream of the US 101 crossing has scoured into stiff glacial till for most of its length, which is relatively resistant to erosion. The exposed glacial till within the streambed supplies sediment to the system at a slow rate as flowing water gradually erodes deeper into the till. The potential for the stream to be modified by the landscape of the golf course, the length the stream is piped beneath the golf course, and the glacial features in the channel upstream of the US 101 crossing, could contribute to limited sediment supply downstream. Due to the potentially limited supply of sediment transported to the downstream system, the potential for aggradation may be low, and could increase the risk of incision.

A longitudinal profile from the existing HDPE pipe outlet that runs beneath the golf course to approximately 300 feet downstream of the US 101 culvert outlet does not indicate a headcut or other discontinuity in the channel grade except at the culvert outlet. The culvert is currently perched, and if replaced may provide an opportunity for a headcut to develop at or upstream of the culvert outlet.

3.4.3 Floodplain Flow Paths

The Unnamed Tributary to Skookum Creek/US 101 culvert crossing project is not within a mapped 100-Year floodplain according to May 1988 FEMA maps of the Skookum Creek floodplain, which does not extend across US 101 within the project area.

The upstream reach of the unnamed tributary is highly confined and has minimal access to its floodplains within the deeply incised channel. Downstream of the US 101 crossing, the channel is moderately incised with bank heights ranging from 2 to 4 feet. Banks in sections of the downstream reach appear to allow flow into the floodplain during high flows.

3.4.4 Channel Migration

The reach upstream of the US 101 crossing appears to provide minimal opportunity for channel migration. The channel upstream of the proposed crossings appears to have incised several feet, currently limiting the potential for lateral migration to only localized bank erosion. However, bank erosion was minimal as the banks were comprised of hardpan. Large amounts of incision could increase the potential for bank erosion increasing the risk for future lateral migration. There is evidence of minor channel migration in the reach downstream of the US 101 crossing, including undercut banks and root scour. However, the signs are very minor as the reach is straight and incised.

3.4.5 Existing LWM and Potential for Recruitment

The riparian corridor along the reach upstream of the US 101 crossing is densely vegetated, primarily with small trees, and shrubs. The reach appears to contain relatively few large trees which are scattered along the reach, which limits the potential for wood recruitment. Downstream of the culvert crossing, the riparian corridor contains more large trees and evidence of channel migration, which increases the opportunity for wood recruitment. Existing riparian forest consists primarily of deciduous trees both upstream and downstream of the US 101 crossing.

Large woody material (LWM) is limited throughout the project area. The HDPE pipe that runs beneath the golf course prevents transport of LWM from upstream reaches. Therefore, all potential for LWM recruitment is from localized recruitment such as deadfall, windfall, and bank erosion within the project reach.

3.4.6 Sediment Size Distribution

The streambed substrate is composed of exposed till as a result of channel incision, with several sections containing fine to coarse gravels (Figure 15). On August 29, 2019, three Wolman pebble counts were performed approximately 65 feet upstream of the existing culvert, between bankfull width measurements 1 and 2. The grain size distribution is dominated by gravels with a D_{50} of 0.81 inches, as summarized in Table 1.

Figure 15 Streambed material photo upstream of US 101 crossing

Table 1 Sediment properties downstream of US 101 Crossing

Particle	Diameter (in)
D_{15}	0.09
D_{35}	0.54
D_{50}	0.81
D_{84}	1.65
D_{95}	2.25
D_{100}	3.54

Figure 16 shows the cumulative distribution of sediment sizes at the location of the pebble count.

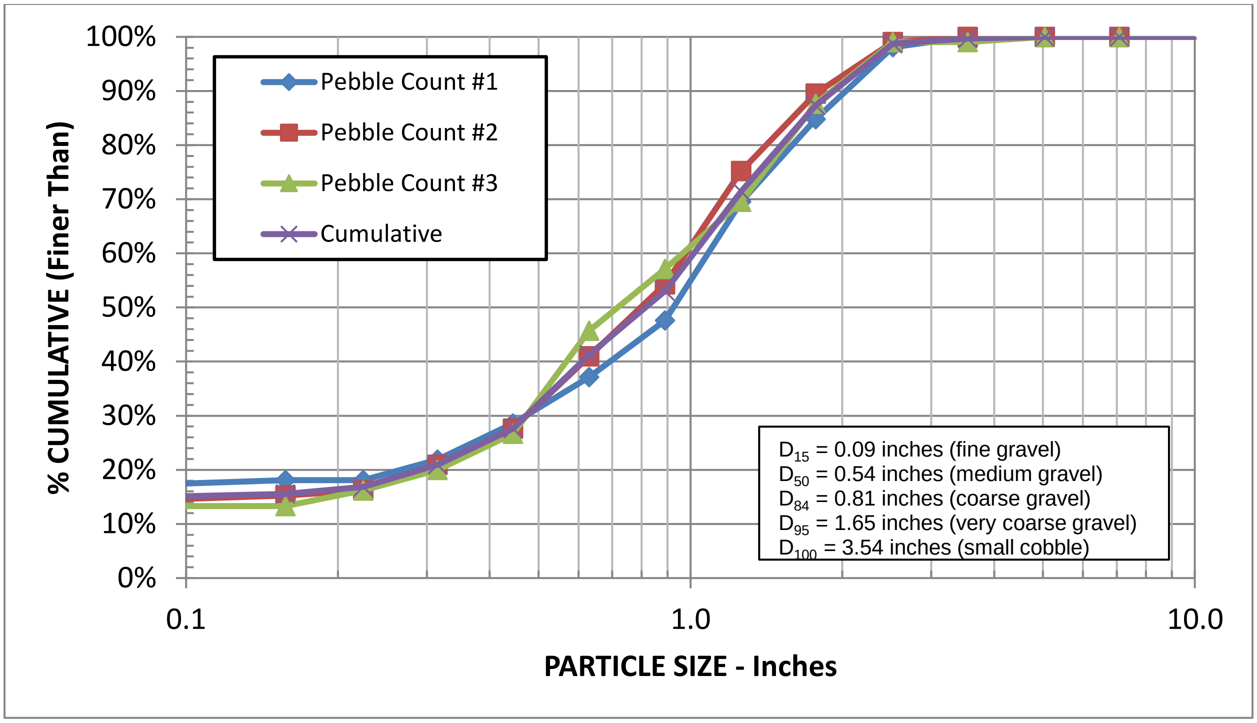


Figure 16 Sediment size distribution upstream of US 101 crossing

3.5 Groundwater

The Washington State Department of Ecology (ECY) well log database, EIM database, and the USGS NWIS were queried for groundwater level data. One water well (Well Report ID 35466) was identified in the upper reach of the stream channel, approximately 1,500 feet upstream of the crossing and appears to serve the golf course. The static water level was found to be 7 feet below the top of the well.

No obvious signs that groundwater might be close to the surface other than the flow in the channel were observed.

4.0 Fish Resources and Site Habitat Assessment

4.1 Fish Use

The portion of the unnamed tributary to Skookum Creek that is located within the project site supports the occurrence of fall-run coho salmon (*Oncorhynchus kisutch*), chum salmon (*Oncorhynchus keta*), winter-run steelhead (*Oncorhynchus mykiss*) and coastal cutthroat trout (*Oncorhynchus clarkii clarkii*) (WDFW PHS data 2019a; WDFW Salmonscape 2019b; Streamnet 2019). Of these species, winter steelhead that inhabit the watershed are part of the Puget Sound Distinct Population Segment (DPS) and are federally listed as threatened under the Endangered Species Act (ESA) of 1973. Besides salmonids, several additional fish species, including sculpin and lamprey, also inhabit the watershed. Table 2 provides a list of native fish potentially found in Skookum Creek and its tributaries. No fish were observed during the August 5, 2019 fish resource and site habitat site visit, and flows within the stream were very low with only a few inches of water depth or less (other than the small plunge pool at the culvert outlet). Figure 16 presents a map of lower Skookum Creek, the unnamed tributary, and the fish passage features that were documented by WDFW during their fish passage inventory and habitat surveys.

Table 2 Native fish species potentially found

Species	Source (Assumed, Mapped, or Documented)	Pre-Existing Fish Use Surveys (spawner surveys or other biological observations)	Life History Present (Egg, Juvenile, Adult)	Limiting Habitat Factors	Stock Status and/or ESA Listing
Coho (*Onchorhynchus kisutch*)	Documented	Statewide Integrated Fish Distribution (SwIFD), Salmonscape, PHS	Juvenile, Adult	Spawning and Rearing	Not Warranted
Fall Chum (*Onchorhynchus keta*)	Documented	SwIFD, Salmonscape, PHS	Juvenile, Adult	Spawning and Rearing	Not Warranted
Winter Steelhead (*Onchoryhnchus mykiss*)	Documented	SwIFD, Salmonscape, PHS	Juvenile, Adult	Spawning and Rearing	Federally Threatened
Coastal Cutthroat (*Onchoryhnchus clarkii clarkii*)	Documented	SwIFD, Salmonscape, PHS	Egg, Juvenile, Adult	Spawning and Rearing	Not Warranted
Sculpin (*Cottus*)	Assumed	None	Egg, Juvenile, Adult	Spawning and Rearing	Not Warranted
Lamprey (Lampreta)	Assumed	None	Egg, Juvenile, Adult	Spawning and Rearing	Not Warranted

4.2 Existing Habitat

Skookum Creek is a significant watershed in South Puget Sound, with numerous tributaries providing habitat for salmonids. Land use at higher elevations is predominately timber production, with livestock and pasture/hayfields in the mid and lower valleys. The Skookum Creek watershed provides spawning and rearing habitat for coho, chum, steelhead, and cutthroat trout throughout the mainstem and accessible reaches of its tributaries. These anadromous species are part of Puget Sound stocks and access Skookum Creek through the Little Skookum Inlet off Totten Inlet in south Puget Sound.

In addition to fish passage barriers in the upper watershed, the most significant biological impairments are habitat diversity and quantity, sediment load and transport, and summer water temperatures. The unnamed tributary that crosses US 101 at MP 354.01 provides rearing and migratory habitat for salmonids and other fish species.

4.2.1 Immediate Crossing

The current crossing is undersized for the channel and is classified as a barrier to fish passage due to an excessive hydraulic drop at the culvert outlet. Coho, chum, and steelhead are not known to migrate above the culvert at any flows and the barrier condition of the culvert is assumed to be precluding both adult and juvenile salmonids upstream passage.

4.2.2 Quality Within Reach

In-stream habitat complexity and spawning habitat is limited in the project reach. Both upstream and downstream of the culvert crossing, most of the substrate is dominated by fines. Downstream of the US 101 crossing, the unnamed tributary flows through a mixed forested riparian area next to US 101 comprised primarily of alder (*Alnus rubra*) and big leaf maple (*Acer macrophyllum*), with some fir trees (*Pseudotsuga menziesii*) south of the right bank. The shrub layer is dominated by Himalayan blackberry (*Rubus armeniacus*) near the road prism and where the stream emerges from the forest cover to cross pasture, and has a mix of native species including salmonberry (*Rubus spectabilis*) in the forested areas. The riparian corridor narrows and is dominated by alders and Himalayan blackberry as the stream flows north through pasture areas. Mixed mature forest riparian habitat occurs at the confluence with Skookum Creek.

A small plunge pool is present at the culvert outlet, where the stream drops approximately 2 feet from the culvert over some rip rap. Approximately 40 feet downstream of the culvert, the stream channel narrows and becomes incised, with banks up to approximately 4 feet high in places. The substrate has areas of hardpan and clay and fines in the substrate, with small gravel in some areas. Downstream of theWSDOT right-of-way, the channel widens and the banks are lower. A tributary enters the stream from the river bank approximately 100 feet downstream of the culvert outlet.

In-stream habitat in this reach lacks complexity and large woody material (LWM) but provides potential rearing and migratory habitat. Forest and shrub cover in the downstream reach provide good shading and some LWM potential. Upstream the canopy cover is less and there is lower potential for LWM recruitment. The distance from the crossing to the confluence with Skookum Creek is approximately 0.3 miles. Skookum Creek continues for approximately 1.2 miles to where it enters Little Skookum Inlet, and on to Totten Inlet off Puget Sound.

Upstream of the US 101 crossing, the unnamed tributary outfalls from a 36-inch HDPE pipe that runs beneath a fairway of a golf course. At the outfall, there is a large pool and then the channel reach narrows and becomes deeply incised along the left bank. Much of the upstream habitat is comprised of a low gradient channel with an incised left bank and a low floodplain off the right bank.

The upstream reach flows through mostly deciduous canopy with some conifers comprised primarily of alder, and big leaf maple, with some fir. There is a dense shrub understory with native and non-native species including salmonberry, vine maple (*Acer circinatum*), and Himalayan blackberry. The mature forest and shrub cover provides good shading, nutrient inputs, and moderate potential LWM recruitment.

Habitat in this reach is predominantly suited to seasonal migration and rearing, with little spawning gravel, and minimal pool-riffle complexes. There is limited large wood accumulation throughout the stream channel with moderate wood recruitment potential.

4.2.3 Length of Potential Gain

In December 2009, WDFW surveyed 0.9 miles (4,875 feet) of the unnamed tributary upstream of the project site. This upstream reach is conveyed through the Salish Cliffs Golf Club property in the 230-foot long 36-inch HDPE pipe at the upstream extent of our project survey, then a second 50-foot long culvert. Upstream of the pipe and culvert there is a reach of potential habitat. In this upstream reach, WDFW documented 0.09 acre of spawning habitat and 0.2 acres of rearing habitat (WDFW report 997158).

4.2.4 Other Barriers in System

Downstream of the stream crossing under US 101, there are two culverts and one small dam on private agricultural land that have been evaluated by WDFW as barriers to fish passage. One is a partial barrier and the other two are mapped as total barriers. Two other private culvert crossings on driveway and farm access roads are documented as passable (WDFW fish passage report 997158). Downstream of these barriers the unnamed tributary joins the right bank of Skookum Creek and no barriers exist downstream to the mouth at Little Skookum Inlet.

Upstream of the US 101 crossing there are two culvert barriers in the Salish Cliffs Golf Club. These are shown as complete barriers to passage due to the vertical drops at their outlets. The next barrier upstream of the project reach is an undersized HDPE pipe, approximately 230 feet in length that crosses under a fairway on the golf course (WDFW 930897). Further upstream in the golf course property, another culvert approximately 50 feet in length was assessed as a complete passage barrier (WDFW 930898).

4.2.5 Other Restoration Efforts in System

Commercial timberlands dominate the headwaters and upper watershed, while agricultural pasturelands, rural residential and urban development make up the majority of the valley floor through the lowlands.

The Squaxin Island Tribe owns portions of land in the lower reaches of Skookum Creek and its tributaries as it runs through the reservation. The Tribe, along with conservation groups have several completed and ongoing restoration and preservation projects in the Skookum Creek watershed. Tribal restoration projects in the watershed have improved freshwater habitat for salmonids, particularly for the coho run. Where Skookum Creek runs through Tribal property, the Squaxin Island Tribe has set aside 150-foot buffers on each side of the creek to protect ecological functions, and has begun replanting efforts.

The Tribe has also worked with the South Puget Sound Salmon Enhancement Group to dig out the steep, eroded banks of the lower creek. Instead of the near vertical 10-foot wall that previously existed, the streambank is now a gentle slope and creates floodplain connectivity. Additionally, the partners are building logjams to recreate natural conditions of in-stream habitat to help create pools where adult salmon can rest while migrating upstream and rearing juveniles can find refuge.

Work has been undertaken to place additional wood in the tributaries, with substantial LWM and key pieces being added to Reitdorf Creek, a left-bank tributary to Skookum Creek, in 2002 with the use of helicopters. McDonald Creek, a right-bank tributary to Skookum Creek, is the focus of two Family Forest Fish Passage Program projects, each removing partial barriers upstream of a WDFW passable fishway.

The Washington Wildlife and Recreation Coalition is working in partnership with the Squaxin Island Tribe to help acquire and permanently protect 158 acres of wetlands and shorelines along Skookum Creek, using grant funding for the Skookum Valley Wetland Acquisition. The Squaxin Island Tribe's plans to buy up to 614 acres in the Skookum Valley, depending on landowners' willingness, would also be funded by the Skookum Valley Wetland Acquisition grant. This project will protect more than 4 miles of Skookum Creek and an additional 4.4 miles of tributaries, as well as a number of wetlands, stream banks, and forests.

Though there have been restoration efforts on Skookum Creek and other tributaries, there are no known completed or planned future restoration efforts on this tributary.

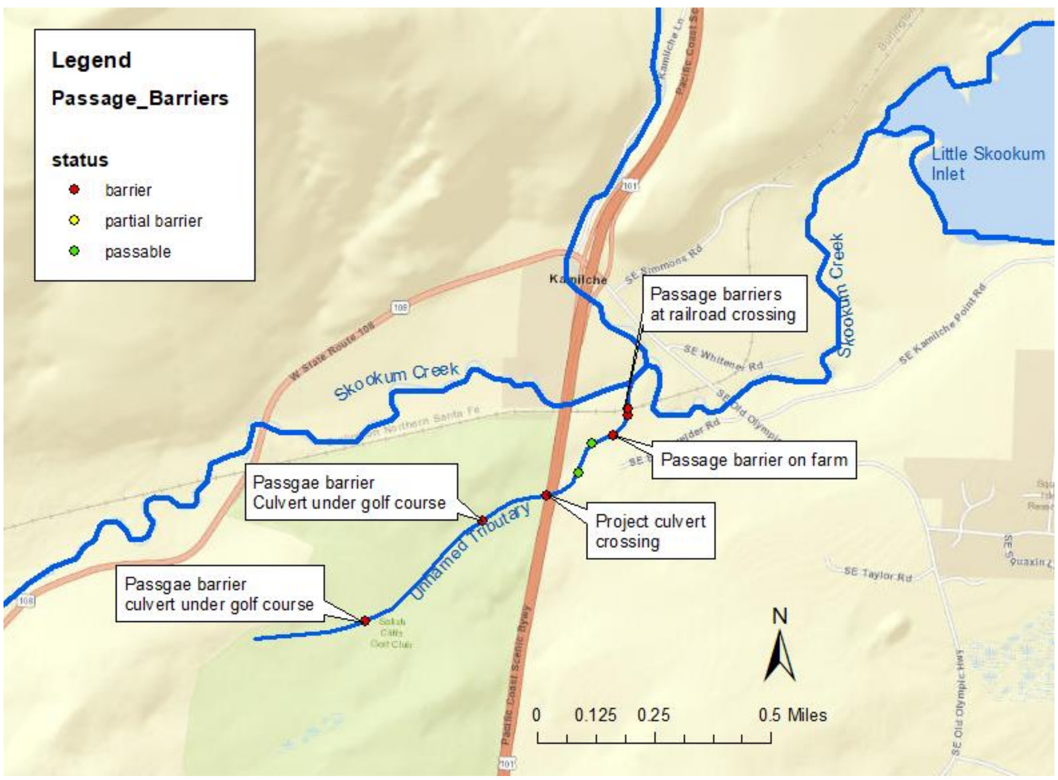


Figure 17 Fish passage features located on the unnamed tributary to Skookum Creek

5.0 Reference Reach Selection

A reference reach was not located within the project area as the stream channel has been highly influenced by the golf course and undersized culvert upstream of the project extents. The reach between the golf course and project culvert is highly incised, with exposed hardpan and a lack of complexity. A reference reach was not located downstream of the crossing either. The downstream reach is channelized, incised and lacks sediment supply due to culverts upstream. Further downstream, a tributary enters the stream approximately 100 feet downstream of the culvert outlet. Bankfull widths downstream of the confluence are not representative of the project site due to an increase in flow from the tributary. A total of three bankfull width measurements were taken within the project area at locations shown in Figure 18 and are summarized in Table 3. Two bankfull width measurements were taken approximately 80 feet and 50 feet upstream of the existing culvert inlet, which measured 5.8 feet and 6.5 feet respectively. One bankfull width measurement was taken downstream of the existing culvert outlet that measured 8.2 feet. During the stakeholder site visit with WDFW it was agreed to use just the downstream bankfull width of 8.2 feet for the design bankfull width. Pebble counts were performed between bankfull widths 1 and 2 and are discussed in Section 3.4.6.

Table 3 Bankfull width summary

BFW #	Bankfull Width	Notes	Used for Design Average BFW
BFW 1	5.8 ft	80 ft upstream of existing US 101 culvert inlet, upstream of the WSDOT right-of-way	No
BFW 2	6.5 ft	50 ft upstream of existing US 101 culvert inlet downstream of the WSDOT right-of-way	No
BFW 3	8.2 ft	40 ft downstream of existing US 101 culvert outlet downstream of the WSDOT right-of-way	Yes

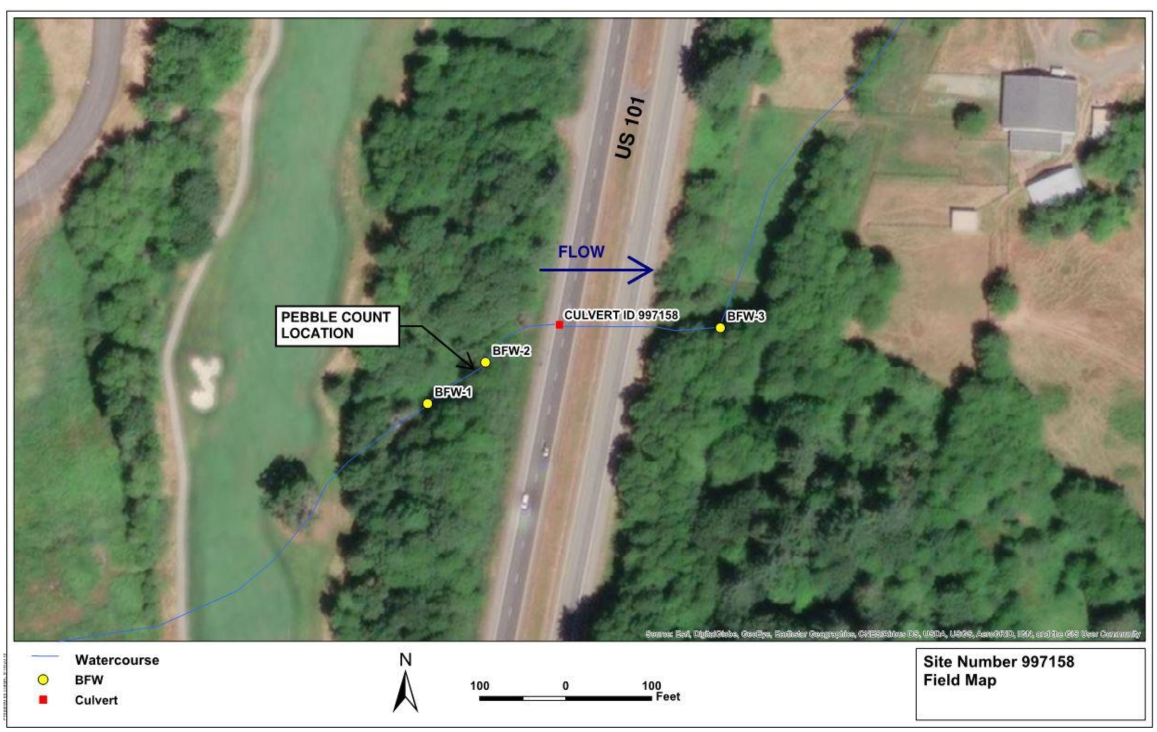


Figure 18 Bankfull width and pebble count measurement locations

6.0 Hydrology and Peak Flow Estimates

Due to lack of stream flow data on the Unnamed Tributary, peak flow estimates for the Unnamed Tributary to Skookum Creek were obtained from the USGS Regression Equation (Mastin, et al., 2016). The Unnamed Tributary has a basin area of 0.24 square miles and a mean annual precipitation within the basin of 64.1 inches (PRISM, 2019). A right bank tributary joins the project's Unnamed Tributary approximately 100 feet downstream of the existing culvert outlet. This tributary has a basin area of 0.43 square miles and a mean annual precipitation within the basin of 62.4 inches (Prism, 2019).

Table 4 and Table 5 show the calculated peak flows and prediction intervals (at a 90% confidence level) for the Unnamed Tributary to Skookum Creek at US 101 and the downstream right bank tributary.

Table 4 Peak flows, Standard Error of Prediction and Prediction Intervals (at a 90% confidence interval) for the Unnamed Tributary to Skookum Creek at US 101

Mean Recurrence Interval (MRI)	Unnamed Tributary at US 101 (cfs)	Standard Error of Prediction	Prediction Interval (lower)	Prediction Interval (upper)
2	**11.8**	43.2	5.90	23.6
5	**18.6**	44.4	9.10	38.1
10	**23.0**	45.6	11.1	47.7
25	**28.7**	48.1	13.3	62.0
50	**32.8**	50.5	14.7	73.1
100	**37.2**	51.8	16.4	84.6
200	**41.5**	54.2	17.6	98.1
500	**47.5**	57.7	19.2	117

Table 5 Peak Flows, Standard Error of Prediction and Prediction Intervals (at a 90% confidence interval) for the Right Bank Tributary

Mean Recurrence Interval (MRI)	Right Bank Tributary Approximately 100 ft Downstream of Project (cfs)	Standard Error of Prediction	Prediction Interval (lower)	Prediction Interval (upper)
2	**19.1**	43.2	9.60	38.1
5	**29.9**	44.4	14.7	61.0
10	**37.2**	45.6	18.0	76.6
25	**46.3**	48.1	21.5	99.7
50	**53.0**	50.5	23.9	117.7
100	**60.3**	51.8	26.6	136.3
200	**67.3**	54.2	28.6	158.2
500	**77.1**	57.7	31.4	189.6

7.0 Hydraulic Analysis

The hydraulic analysis of the existing and proposed US 101 Unnamed Tributary to Skookum Creek crossing was performed using Bureau of Reclamation's SRH-2D Version 3.2.0 (USBR, 2017) computer program, a two-dimensional hydraulic and sediment transport model. It includes the ability to model dynamic interactions between the stream channel and overbanks, roadway overtopping, culverts, and the influence of bridge decks on bridge backwater. Pre- and post-processing of the model was completed using SMS Version 13.0.5 (Aquaveo, 2018). Appendix A contains detailed output from the hydraulic modeling effort.

Two scenarios were analyzed for determining stream characteristics for the Unnamed Tributary to Skookum Creek with the SRH-2D models: 1) existing conditions with the 3 foot diameter concrete culvert and 2) future conditions with the proposed 16 foot hydraulic opening.

7.1 Model Development

7.1.1 Topography

Detailed channel geometry data in the model was obtained from the MicroStation and InRoads files, which were developed from topographic surveys performed by Lin & Associate surveyors. Proposed channel geometry was developed from the proposed grading surface created by HDR Engineering, Inc.

7.1.2 Model Extent and Computational Mesh

The hydraulic model upstream and downstream extents are consistent with the detailed survey boundary, approximately 210 feet upstream of the existing culvert outlet and 280 feet downstream of the existing culvert outlet, measure along the channel centerline. The computational mesh elements was a combination of patched and paved (triangular) elements, with finer resolution in the channel and larger elements in the floodplain (Figure 19).

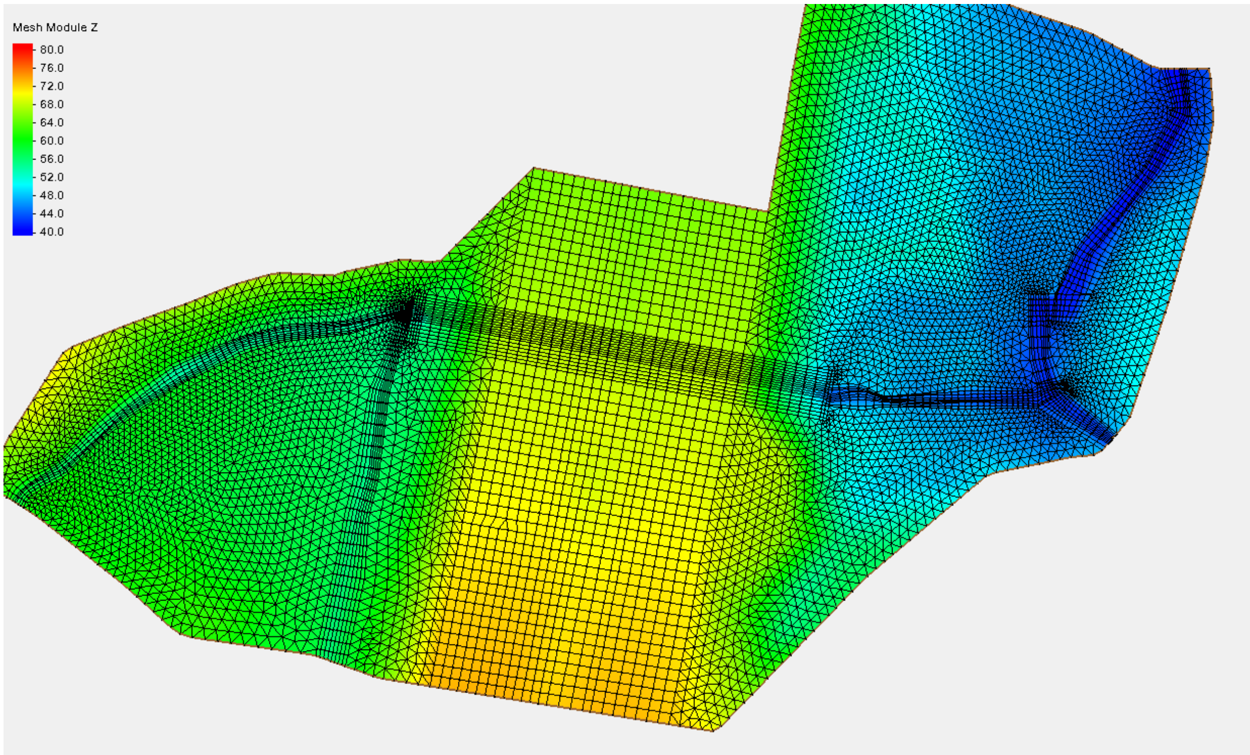


Figure 19 Existing computational mesh with underlying terrain

7.1.3 Roughness

Manning's n values were estimated based of site observations, aerial photography and standard engineering values (Chow, 1959) and are summarized below (Table 6). Aerial photography in combination with detailed survey information to determine divisions between the roadway, road embankment, and median grass ditch. Roughness in the overbanks represents light brush and trees in the riparian areas.

Table 6 Summary of roughness coefficients

Land Cover	Manning's Roughness Coefficient
Channel	0.045
Floodplain	0.08
Median Grass Ditch/Road Embankment	0.03
Road	0.02

7.1.4 Boundary Conditions

Model simulations were performed using multiple quasi-steady state discharges ranging from the 2-year to 500-year peak flow events summarized described in Section 6.0. External boundary conditions were applied at the upstream and downstream extents of the model and remained the same between the existing and proposed conditions runs. A constant flow rate was specified at the upstream external boundary condition, while a normal depth rating curve was specified at the downstream boundary. An additional constant inflow rate is specified at the right bank tributary downstream of the crossing. The flow values for Unnamed Tributary to Skookum Creek and the right bank tributary external boundary conditions are detailed in Table 4 and **Error! Reference source not found.**, respectively. The downstream normal depth boundary condition rating curve was developed within SMS using the existing terrain, assuming a downstream slope of 3% as measured from the survey and a composite roughness of 0.05.

An HY-8 internal boundary condition was specified in the existing conditions model to represent the existing circular concrete culvert crossing. The existing crossing was modeled as a 3 foot diameter circular pipe within HY-8. A manning's roughness of 0.012 was assigned to the culvert. The culvert was assumed to be unobstructed and free from any stream material within the barrel.

7.1.5 Model Geometries

Two geometries were developed for simulation with SRH-2D, representing existing and proposed conditions. The existing conditions includes the existing circular concrete culvert crossing of US 101. The existing condition geometry was modified to develop the proposed conditions by removing the existing culvert and associated internal boundary conditions. Additionally the terrain was updated to reflect the proposed grading and 16-foot span hydraulic opening. The walls of the proposed structure were modeled as voids in the computational mesh. Model geometry outside of the proposed improvements are the same for the proposed conditions as the existing condition.

7.2 Model Results

Hydraulic results were summarized and compared at common locations between the existing and proposed simulations (Figure 20). The upstream cross section is located at approximate station 5+03 and is at the inlet of the proposed hydraulic opening. Downstream the cross section was located at station 2+30, 50 feet downstream of the existing culvert outlet. Hydraulic variables reported include water surface elevation, depth, velocity and shear stress averaged along the cross section. Appendix A contains the more detailed hydraulic output.

In addition to cross section results, results were summarized along the longitudinal profile. Both existing and proposed conditions use the same alignment for reporting results (Figure 21).

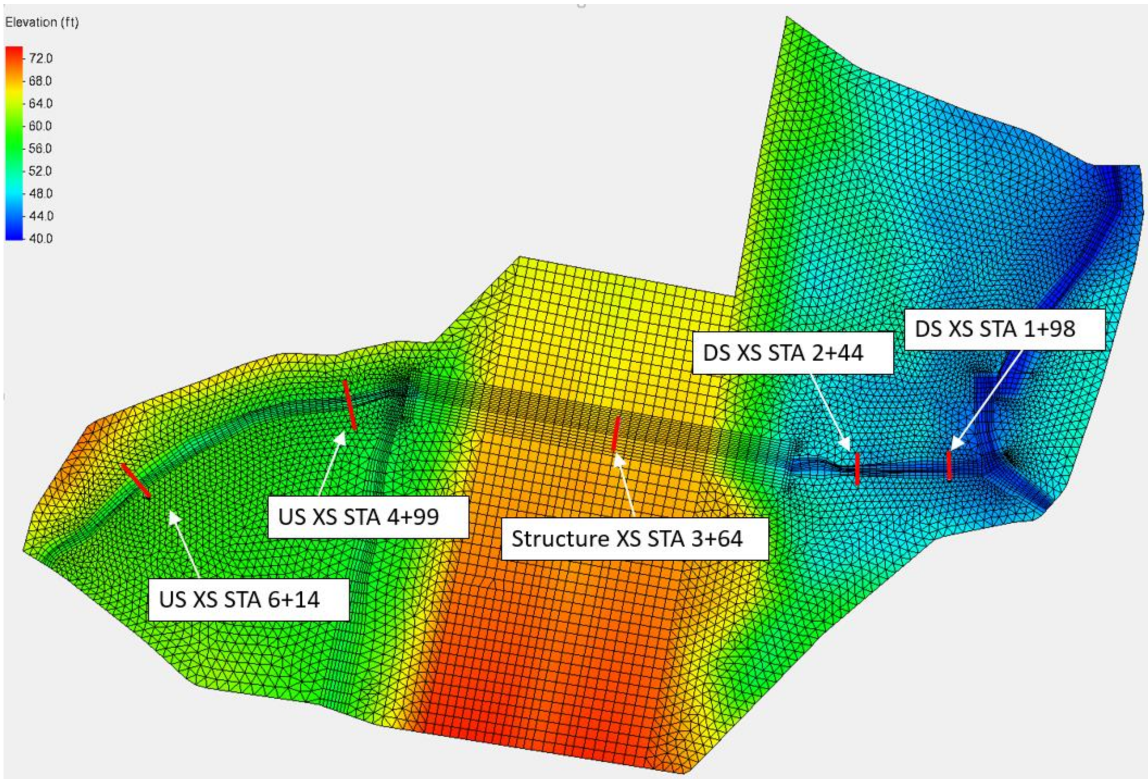


Figure 20 Locations of cross sections used for results reporting

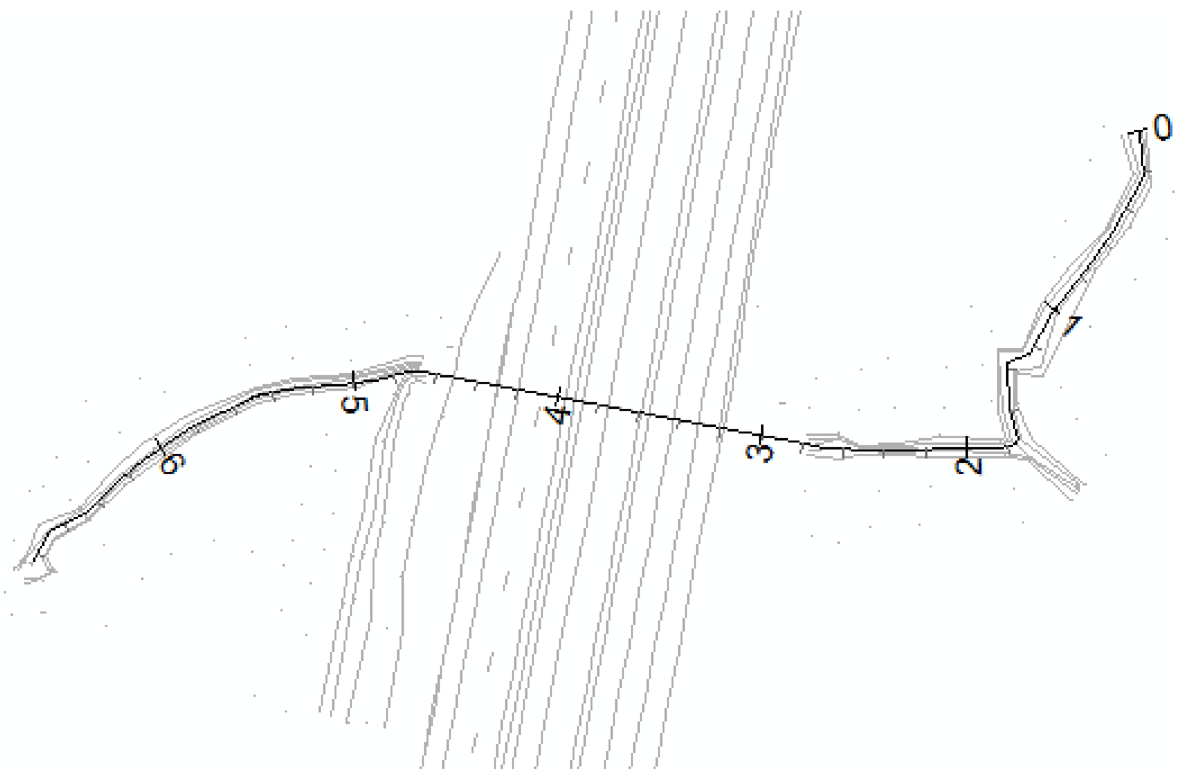


Figure 21 Longitudinal profile stationing for existing and proposed conditions

7.2.1 *Existing conditions – 3 foot diameter concrete culvert*

Existing conditions hydraulic results are summarized for the upstream and downstream cross sections in Table 7 below. Under existing conditions, the culvert causes a backwater upstream for the range of flows simulated (Figure 22). Pressure flow conditions first occur between the 50 and 100-year flow events, when the headwater elevation exceeds 54.9 feet. The existing roadway was not overtopped over the range of flow events modeled.

As a result of the backwater, the upstream depths are greater than the downstream reach. In addition, the upstream shear and velocities are lower than their downstream counter parts. Upstream average channel velocities varied from 3.1 feet per second (ft/sec) during the 2-year event to 4.5 ft/sec during the 50-year event. At the downstream cross sections velocities ranged from 2.6 ft/sec at the 25-year event to 5.4 ft/sec at the 500-year event. Shear varied from 0.8 lb/ft^2 to 1.4 lb/ft^{2}at the upstream cross sections during the 2-year and 50-year events, respectively. Larger shear values were present in the downstream cross sections, ranging from 1.2 lb/ft^2 at multiple events to 2.5 lb/ft^2 at the 500-year event. When looking at the entire model domain, the largest velocities occurred at the culvert outlet and the steeper, downstream reach of the channel (Figure 23).

Table 7 Hydraulic results for existing conditions

Hydraulic Parameter	Cross section station (STA)	2-year	25-year	50-year	100-year	500-year
Average water surface elevation (ft)	1+98 (DS)	43.4	44.3	44.5	44.7	45.2
	2+44 (DS)	45.4	45.9	46.0	46.1	46.3
	3+64 (Culvert)	NA	NA	NA	NA	NA
	4+99 (US)	54.2	54.8	54.9	55.1	55.4
	6+14 (US)	56.4	57.1	57.2	57.4	57.6
Max depth (ft)	1+98 (DS)	0.9	1.8	2.0	2.2	2.7
	2+44 (DS)	0.8	1.3	1.4	1.5	1.7
	3+64 (Culvert)	NA	NA	NA	NA	NA
	4+99 (US)	1.1	1.7	1.9	2.0	2.4
	6+14 (US)	1.3	1.9	2.1	2.3	2.5
Average velocity (ft/s)	1+98 (DS)	3.8	2.7	2.8	2.6	2.6
	2+44 (DS)	4.6	5.1	5.4	5.6	6.2
	3+64 (Culvert)	NA	NA	NA	NA	NA
	4+99 (US)	3.1	3.8	4.0	4.3	3.3
	6+14 (US)	3.5	4.3	4.5	3.6	3.9
Average shear (lb/ft^2)	1+98 (DS)	0.5	0.5	0.4	0.4	0.5
	2+44 (DS)	1.4	2.0	2.1	2.3	2.6
	3+64 (Culvert)	NA	NA	NA	NA	NA
	4+99 (US)	0.8	1.0	1.1	1.1	1.0
	6+14 (US)	1.0	1.4	1.4	1.2	1.3

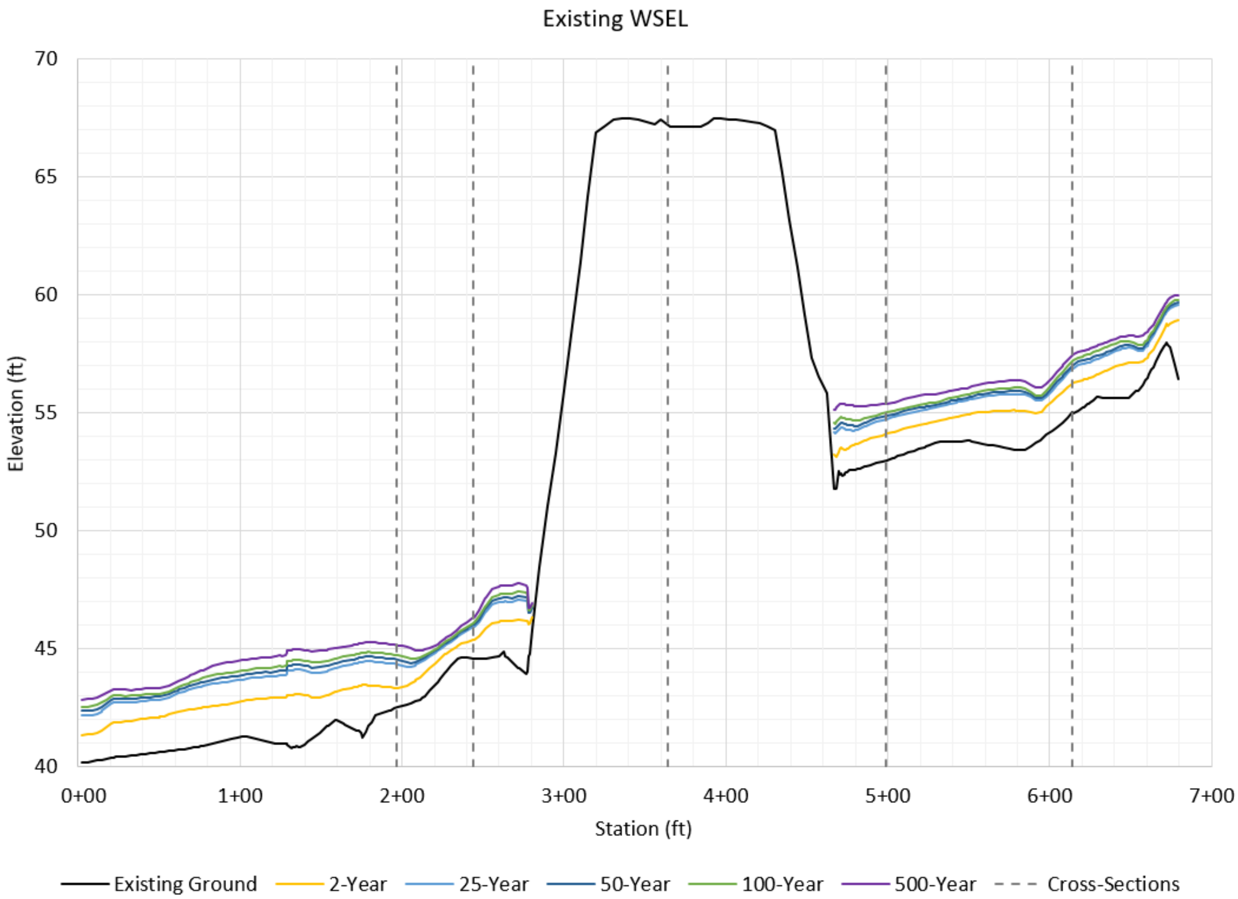


Figure 22 Existing conditions water surface profiles

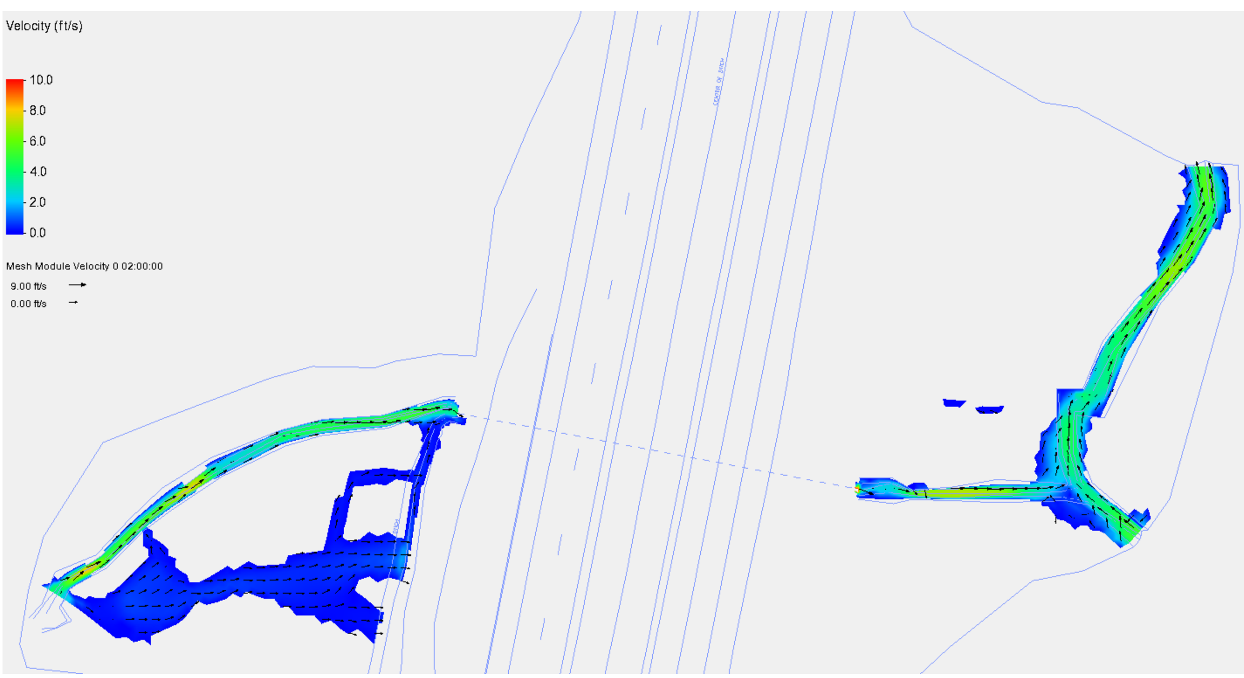


Figure 23 Existing conditions 100-year velocity map

7.2.2 Future conditions – Proposed 16 Foot Span Structure

Proposed conditions hydraulic results are summarized for the upstream and downstream cross sections in Table 8 and within the proposed crossing in **Error! Reference source not found.**. The larger proposed structure reduced water surface elevations upstream and did not result in any backwater (Figure 24). The 100-year water surface elevation upstream of the crossing was decreased by about 2 feet when compared to existing conditions.

With the removal of the backwater condition, upstream channel velocities increased from existing conditions, varying from 3.1 ft/sec during the 2-year event to 5.3 ft/sec during the 500-year event. Within grading extents at STA 2+44, velocities decrease by 1.2 ft/s at the 100-year event from existing to proposed conditions due to widening the proposed channel. At the downstream cross section, there are vertical walls in the existing conditions and the proposed conditions have 2:1 side slopes for constructability purposes. This decreases velocities by increasing the width greatly and barely decreasing the depth from existing to proposed conditions. The downstream proposed conditions velocities vary from 3.1 ft/sec to 5.2 ft/sec.

Similar to the velocity results, shear increases upstream of the crossing compared to downstream conditions. Upstream, it increases from the existing conditions varying from 0.9 lb/ft^2 to 1.8 lb/ft^2. At the downstream cross section, shear values vary from 0.4 lb/ft^2 to 1.6 lb/ft^2. The hydraulics under the proposed crossing indicate this reach is a transition from the reach upstream of the crossing to the downstream reach. Velocities, depths, and shear under the proposed crossing are all between the results of the existing upstream and downstream cross section results. The proposed surface decreases the change between the upstream and downstream shear, depth and velocities, thus creating a more equilibrated reach. When looking at the entire model domain, proposed velocities upstream of the crossing increased compared to existing conditions (Figure 25).

Table 8   Hydraulic results for proposed conditions

Hydraulic Parameter	Cross section station (STA)	2-year	25-year	50-year	100- year	500-year
Average water surface elevation (ft)	1+98 (DS)	43.4	44.3	44.5	44.7	45.2
	2+44 (DS)	45.5	45.9	46.0	46.1	46.3
	3+64 (Culvert)	49.0	49.4	49.5	49.6	49.7
	4+99 (US)	53.0	53.4	53.4	53.5	53.7
	6+14 (US)	56.4	57.1	57.2	57.4	57.6
Max depth (ft)	1+98 (DS)	0.9	1.8	2.0	2.2	2.7
	2+44 (DS)	0.8	1.2	1.3	1.4	1.6
	3+64 (Culvert)	0.7	1.1	1.2	1.3	1.4
	4+99 (US)	0.7	1.1	1.2	1.3	1.4
	6+14 (US)	1.3	1.9	2.1	2.3	2.5
Average velocity (ft/s)	1+98 (DS)	3.7	2.8	2.8	2.6	2.6
	2+44 (DS)	3.1	3.9	4.1	4.4	4.9
	3+64 (Culvert)	3.2	4.1	4.3	4.6	5.3
	4+99 (US)	3.1	4.1	4.3	4.6	5.3
	6+14 (US)	3.5	4.4	4.5	3.6	4.0
Average shear (lb/ft^2)	1+98 (DS)	1.0	0.5	0.5	0.5	0.4
	2+44 (DS)	0.9	1.1	1.2	1.3	1.4
	3+64 (Culvert)	0.9	1.3	1.4	1.5	1.8
	4+99 (US)	0.9	1.3	1.4	1.5	1.8
	6+14 (US)	1.0	1.4	1.4	1.2	1.3

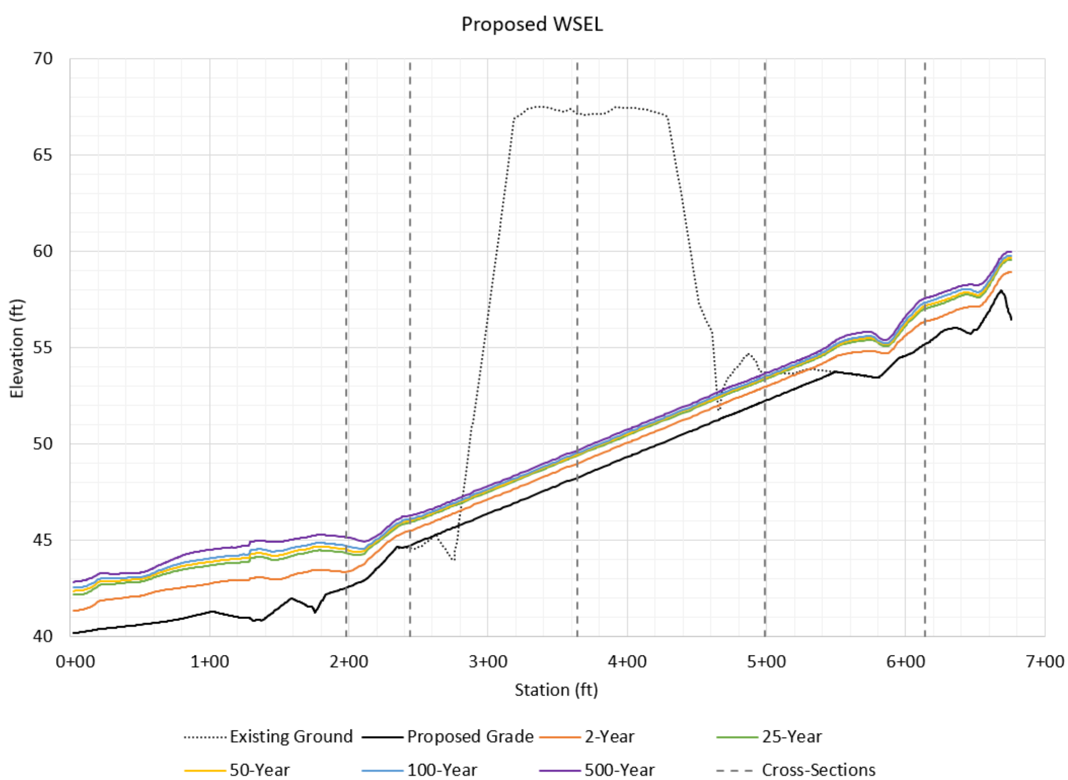


Figure 24   Proposed conditions water surface profiles

Figure 25 Proposed conditions 100-year velocity map

8.0 Fish Passage Design Methods Selection

8.1 Design Methodology Selection

The WCDG contains methodology for five different types of crossings: No-Slope Culverts, Stream Simulation Culverts, Bridges, Temporary Culverts or Bridges, and Hydraulic Design Fishways. The permanent federal injunction allows for the use of the stream simulation method and bridge design method unless extraordinary circumstances exist on site. According to the WCDG, a bridge should be considered for a site if the Floodplain Utilization Ratio (FUR) is greater than 3.0, the stream has a bankfull width of greater than 15 feet, the channel is believed to be unstable, the slope ratio exceeds 1.25 between the existing channel and the new channel, or the culvert would be very long. Using these design criteria, stream simulation design was deemed the most appropriate method for this crossing because the stream has a bankfull width of less than 15 feet and the channel is confined.

8.2 Stream Simulation Criteria

One of the criteria for using stream simulation is the Floodplain utilization Ratio (FUR). The FUR is defined as the flood-prone width (FPW) divided by the bankfull width. The FPW is the water surface width at twice the bankfull depth, or the width at the 50-year to 100-year flood. A ratio of under 3.0 is considered a confined channel and above 3.0 is considered an unconfined channel. Crossings using the stream simulation design methodology should be confined with a FUR of less than or equal to 3.0. The entire project reach of the Unnamed Tributary to Skookum Creek, outside of the culvert backwater influence, has a FUR of less than 3.0 and is considered a confined channel. Approximately 60 feet upstream of the existing culvert the FUR is 1.4, when dividing the modeled 100-year top width by the modeled 2-year top width. It should be noted that flow jumps out of the channel near the upstream end of the model near the golf course HDPE pipe outlet. Flow then spreads out into the right overbank and a portion of it rejoins the channel approximately 50 feet downstream, while the remainder of overbank flow continues until it hits the US101 road embankment, where it re-enters the main channel directly upstream of the culvert inlet. This floodplain width was not included in the FPW and FUR calculations because the floodplain activation is likely caused by the upstream pipe outlet scour or construction. Additionally, the flow that leaves the channel is very minimal and the SRH-2D model estimates it at approximately 1 cfs at the 100-year flow event.

8.2.1 Culvert Span and Length

The WCDG recommends sizing the span of the proposed structure based on the agreed upon bankfull width, with the span being 1.2 x bankfull width + 2 feet (WCDG Equation 3.2). Using this equation, along with the modelled bankfull width of 8.2 feet discussed in Section 4.2, results in a structure span of 11.8 feet. The proposed culvert length is 155 feet in length, assuming the road embankment slopes are not impacted. Effort should be made during later phases to reduce the total length of the culvert to the extent practicable. Per the WCDG, if a structure length is more than 10 times its width then the structure width shall be increased by 30 percent. This crossing length exceeds this threshold and therefore an increase by 30 percent results in a minimum structure span of 15.3 feet. Rounding up to the nearest whole foot results in a recommended structure span of 16 feet.

8.2.2 Backwater and Freeboard

The WCDG recommend the prevention of excessive backwater rise and increased main channel velocities during floods that might lead to scour of the streambed and coarsening of the stream substrate, allow the free passage of debris expected to be encountered, and generally suggests a minimum 2 foot freeboard for streams of this size. It is practicable to meet the minimum 2 feet of freeboard at this crossing, as the road embankment height is over 17 feet above the proposed streambed elevation.

An additional consideration is that a minimum of 5 feet above the thalweg should be provided if practicable for constructability, future maintenance, and monitoring activities. The proposed 100-year depth at the crossing is approximately 1.3 feet, adding 2 feet of freeboard does not meet the minimum recommended 5 foot of clearance. Therefore, the recommended structure should have 5 feet of clearance from the thalweg and assuming 3 feet of countersink the culvert rise would be 8 feet. The proposed structure does not cause any backwater (Figure 24).

8.2.3 Channel Planform and Shape

The WCDG require that the channel planform and shape mimic conditions within a reference reach. The proposed channel shape includes 10H:1V slopes between the toes and 2H:1V bank slopes to create a channel similar to the observed existing channel shape Figure 26.

Channel habitat features will be implemented to create channel complexity, see Section 9.4 for further descriptions of the channel habitat features.

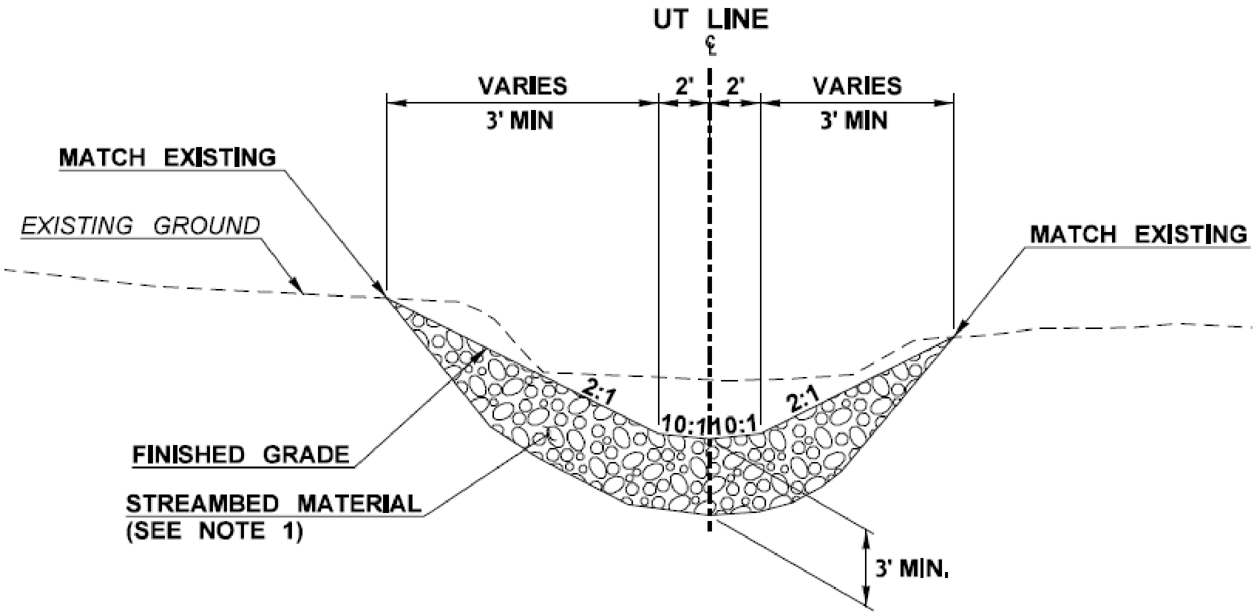


Figure 26 Typical channel section

8.2.4 *Floodplain Continuity and Lateral Migration through Structure*

The WCDG requires that structures account for lateral channel movement that will occur in their design life and that the design channel maintains floodplain continuity. The existing channel upstream and downstream of the project are highly confined and have very limited ability to migrate laterally. Additionally the structure span has been increased by 30% due to its length, which will allow for some level of migration.

8.2.5 *Channel Gradient*

The WCDG recommends that the proposed culvert bed gradient not be more than 25% steeper than the existing stream gradient upstream of the crossing (WCDG Equation 3.1). The proposed channel gradient is 2.94% and the slope upstream of the project is approximately 3.0%, resulting in a slope ratio of 0.98.

There have been ongoing discussion about potentially shortening the stream grading upstream of the crossing to keep the proposed stream grading within the WSDOT right-of-way. If it is determined that the stream grading will be kept within the WSDOT right-of-way the proposed channel gradient would increase to approximately 3.3%. This would result in a slope ratio of 1.1, which is still less than the WCDG recommendation. It is not anticipated that this increase in slope would impact the structure width or freeboard requirement presented in the current PHD. However, the increase in slope will likely have an impact on scour and long-term degradation concerns that will need to be accommodated during future phases of design.

9.0 Streambed Design

9.1 Alignment

The proposed project alignment primarily follows the existing alignment. The only modification to the existing alignment was upstream of the crossing, where the creek centerline was shifted a few feet to the south to minimize hillside excavation to the north. The project will consist of channel grading approximately 50 feet downstream of the crossing to 105 feet upstream of the crossing. The alignment and grading extents are illustrated in design drawings provided in Appendix B.

9.2 Proposed Section

Description of the existing and proposed cross section are presented in Section 8.2.3. A low flow channel will be added in later stages of the project that connect habitat features together and ensure the project is not a low flow barrier. The low flow channel will be as directed by the Engineer in the field.

9.3 Bed Material

The proposed bed material gradation was created using standard WSDOT specification material to mimic the gradation documented in the pebble count as best possible. The proposed mix will consists of 90% Streambed Sediment and 10% 4-in Streambed Cobbles as it is the material that most closely represents the native streambed material observed during the site visit. A comparison of the observed and proposed streambed material size distribution is provided in Table 9. It should be noted that during the site visit that material upstream was scarce with large areas of exposed clay and that it may be necessary to upsize the proposed material as minimal material may be delivered from upstream. Mobility will be assessed during the FHD phase and a determination of the necessity of increasing the proposed material size will be made then.

Table 9 Comparison of observed and proposed streambed material

Particle	Observed Material Diameter (in)	Proposed Material Diameter (in)
D_{15}	0.1	0.02
D_{50}	0.8	0.8
D_{84}	1.7	2.2
D_{95}	2.3	2.5
D_{100}	3.54	4.0

Coarse bands are incorporated into the design. Coarse bands were spaced at approximately 25 feet on center and alternate sides of the culvert to promote thalweg sinuosity. The proposed coarse band material is 50% Streambed Sediment and 50% 6-inch Streambed Cobbles.

9.4 Channel Habitat Features

Large Woody Material will be installed in portions of Unnamed Tributary to Skookum Creek. These LWM installations will provide structures conducive to create stream complexity and geomorphic functions in segments that will have low natural LWM delivery rates while new and impacted riparian areas recover from construction activities related to the installation of the new crossing and the regrading of the stream channels. LWM, in conjunction with habitat boulders and bank-side bioengineering, will also help protect newly constructed banks and will promote long-term bed stability by creating pools, sinuosity, hard points, and channel roughness.

9.4.1 Design Concept

The 75th percentile of key piece density per Fox and Bolton (2007) and Chapter 10 of the Hydraulics Manual recommend 3.3 key pieces per 100 feet of channel. This percentile of wood placement is suggested to compensate for cumulative deficits of wood loading due to development. A conceptual LWM layout has been developed for the Unnamed Tributary project area and is provided in Figure 27. The conceptual layout proposes 11 key pieces. The project reach is 310 feet long yielding 3.5 key pieces per 100 feet of linear channel, exceeding the Fox and Bolton (2007) 75th percentile criteria.

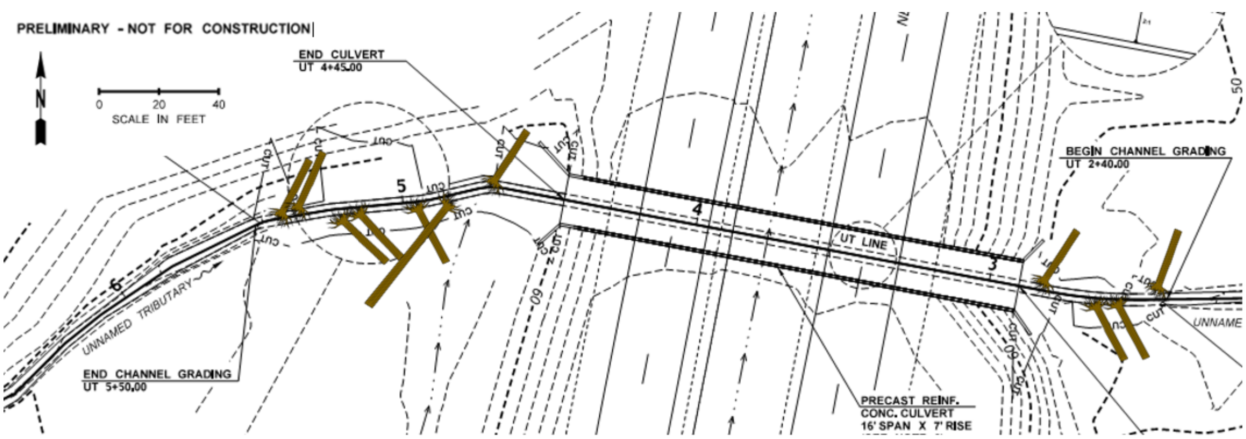


Figure 27 Proposed grading and conceptual wood layout

10.0 Floodplain Changes

This project is not within a FEMA mapped floodplain.

10.1 Floodplain Storage

Floodplain storage is anticipated to be nearly unaffected. Placement of fill associated with the proposed project is limited to the scour hole downstream of the culvert. Material will be removed from the floodplain and channel as a result of replacing undersized culvert with a larger structure, upstream channel grading (cut) and removal of the existing roadway. The installation of a larger hydraulic opening reduces the amount of backwater being stored upstream of the crossing and reduces any peak flow attenuation that was being provided by the smaller, existing culvert. Changes to peak flow reduction was not quantified as the models were run in a quasi-steady state flow with a constant flow rate specified at the upstream boundary of the model.

10.2 Water Surface Elevations

Installation of the proposed structure will eliminate the backwater impacts upstream of the existing culvert, resulting in a reduction in water surface elevation. Preliminary hydraulic results indicate that there is a reduction in water surface elevation of approximately 2 feet during the 100-year event.

11.0 Climate Resilience

WSDOT recognizes climate resilience as a component of the integrity of its structures and approaches the design of bridges, and buried structures through a risk based assessment beyond the design criteria. For bridges and buried structures, the largest risk to the structures will come from increases in flow and/or sea level rise. The goal of fish passage projects is to maintain natural channel processes through the life of the structure and maintain passability for all expected life stages and species in a system.

11.1 Climate Resilience Tools

Climate resilience is evaluated at each crossing using the Climate Impacts Vulnerability Assessment Maps created by WSDOT to assess risk level of infrastructure across the state. The US101 crossing at the Unnamed Tributary to Skookum Creek has been evaluated and determined to be a low risk site based on the Climate Impacts Vulnerability Assessment Maps.

WSDOT also evaluates crossings using the mean percent change in 100-year flood flows from the WDFW Future Projections for Climate-Adapted Culvert Design program. For low or medium risk sites, the 2040 percent increase is used. For high risk sites the 2080 percent increase is used. Appendix C contains the information received from WDFW for this site. The 100-year flow event was chosen to be evaluated, because, as it is an extreme event, if the channel behaves similarly through the structure during this event as it does the adjacent reaches, then it is anticipated this relationship would also be true at lower flows as well.

11.2 Hydrology

For each design WSDOT uses, the best available science for assessing site hydrology. The predicted flows are analyzed in the hydraulic model and compared to field and survey indicators, maintenance history, and any other available information. Hydraulic engineering judgment is used to compare model results to system characteristics; if there is significant variation, then the hydrology is re-evaluated to determine whether or not adjustments need to be made, including adding standard error to the regression equation, basin changes in size or use, etc.

In addition to using the best available science for current site hydrology, WSDOT is evaluating the structure at the 2040 projected 100-year flow event to check for climate resiliency. The design flow for the crossing is 37.2 cubic feet per second (cfs) at the 100-year storm event. The projected increase for the 2040 flow rate is 6.4%, yielding a projected 2040 flow rate of 39.6 cfs.

11.3 Structure Width

The minimum width for a crossing given by Equation 3.2 was 11.8 feet. This structure width was evaluated and it was determined an increase of 30%, resulting in a minimum structure width of 16 feet, was necessary to meet current design practices for structure lengths exceeding 10 times the structure width as further explained in Section 8.2.1. This structure was evaluated at both the 100-year flow event and the projected 2040 100-year flow event. The flow characteristics within the structure produced similar results to those in the adjacent reaches in both cases. The average channel velocity comparisons for these flow rates can be seen in Table 10 below.

Table 10 Velocity comparison for 16 foot structure

	100-Year Velocity (ft/s)	Projected 100-Year Velocity (ft/s)	Difference (ft/s)	Difference (%)
Upstream of Structure	4.62	4.78	0.16	3.5
Through Structure	4.64	4.80	0.16	3.4
Downstream of Structure	4.38	4.50	0.12	2.8
Velocity Ratio	1.00	1.0	-	-

Note: Velocity ratio calculated as Vstructure/Vupstream

11.4 Freeboard and Countersink

The minimum recommended freeboard at this location based on bankfull width is 2 feet at the 100-year flow event. The 100-year flow has an approximate flow depth of 1.27 feet at the 100-year flow event and 1.31 feet at the 2040 projected 100-year flow event. The proposed design provides 3.73 feet of freeboard at the 100-year flow event and 3.69 feet of freeboard at the 2040 projected 100-year flow event, assuming an 8-foot culvert rise and countersink of 3 feet.

Long term degradation and aggregation, contraction scour and local scour were not evaluated for this preliminary hydraulic design and will need to be evaluated during the final design. Pending the outcome of the scour analysis, the preliminary design and depth of countersink will be revised to account for the total potential scour associated with the projected 2040 100-year flow event.

11.5 Summary

The recommended structure size of 16 foot span box culvert with a 7 foot rise and assumed 3 feet of countersink exceeds the minimum freeboard of 2 feet at the projected 2040 100-year flow event. This proposed structure allows for the channel to behave similarly through the structure as it does in the adjacent reaches under the projected 2040 100-year flow event. This will provide a robust structure design that is resilient to climate change and allow the system to function naturally, including the passage of sediment, debris and water in the future.

12.0 Scour Analysis

Scour calculations were not performed during the preliminary design, but will be performed following the procedures outlined in *Evaluating Scour at Bridges HEC No. 18* (Arneson et al. 2012) during final design. Scour components to be considered in the analysis include:

1. Long-term aggradation/degradation
2. General scour (i.e., contraction scour)
3. Local scour

In addition to the three scour components above, potential lateral migration of a channel must be assessed when evaluating total scour at highway infrastructure.

13.0 References

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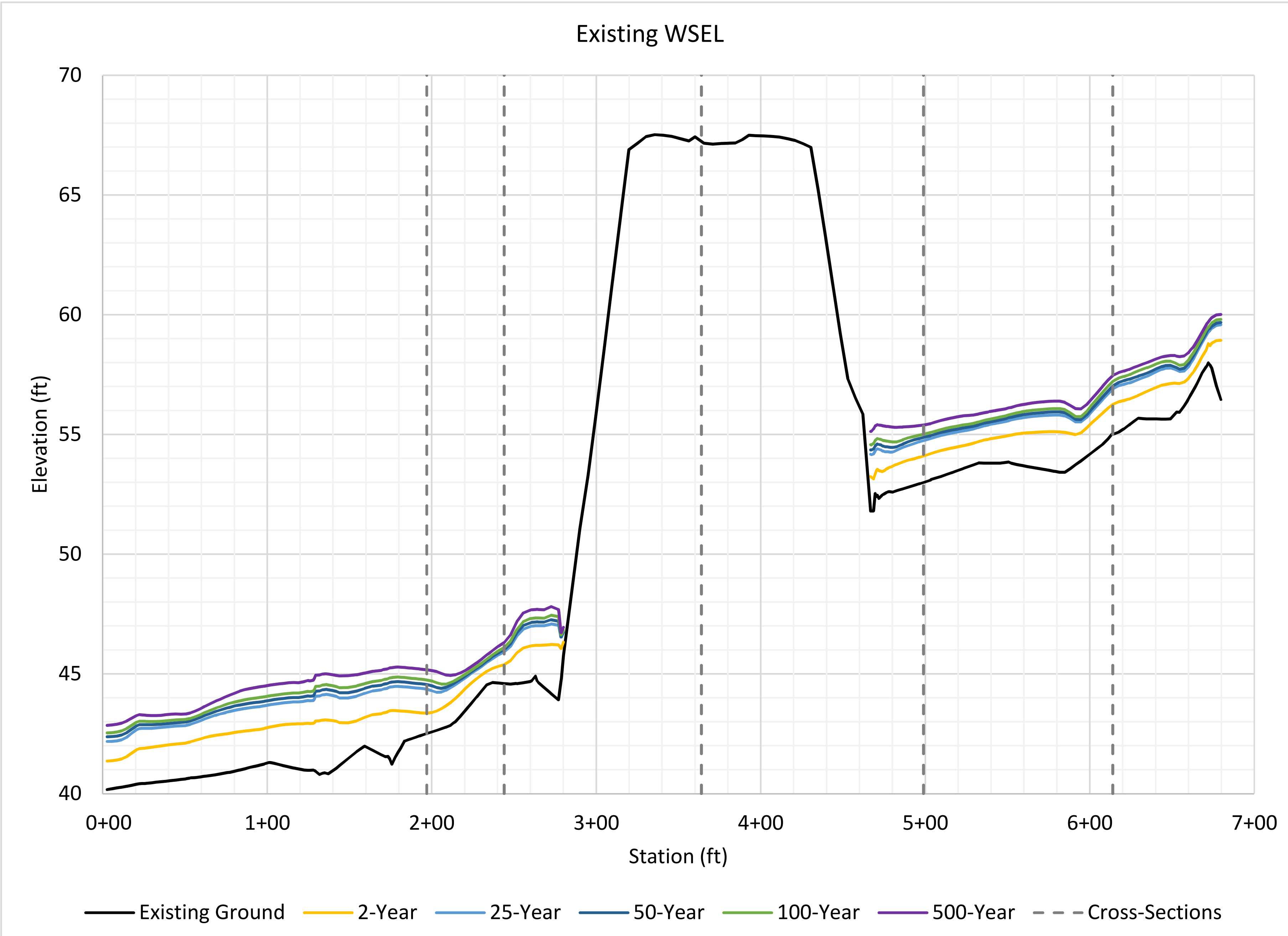
14.0 Appendices

Appendix A – SRH-2D Model Results

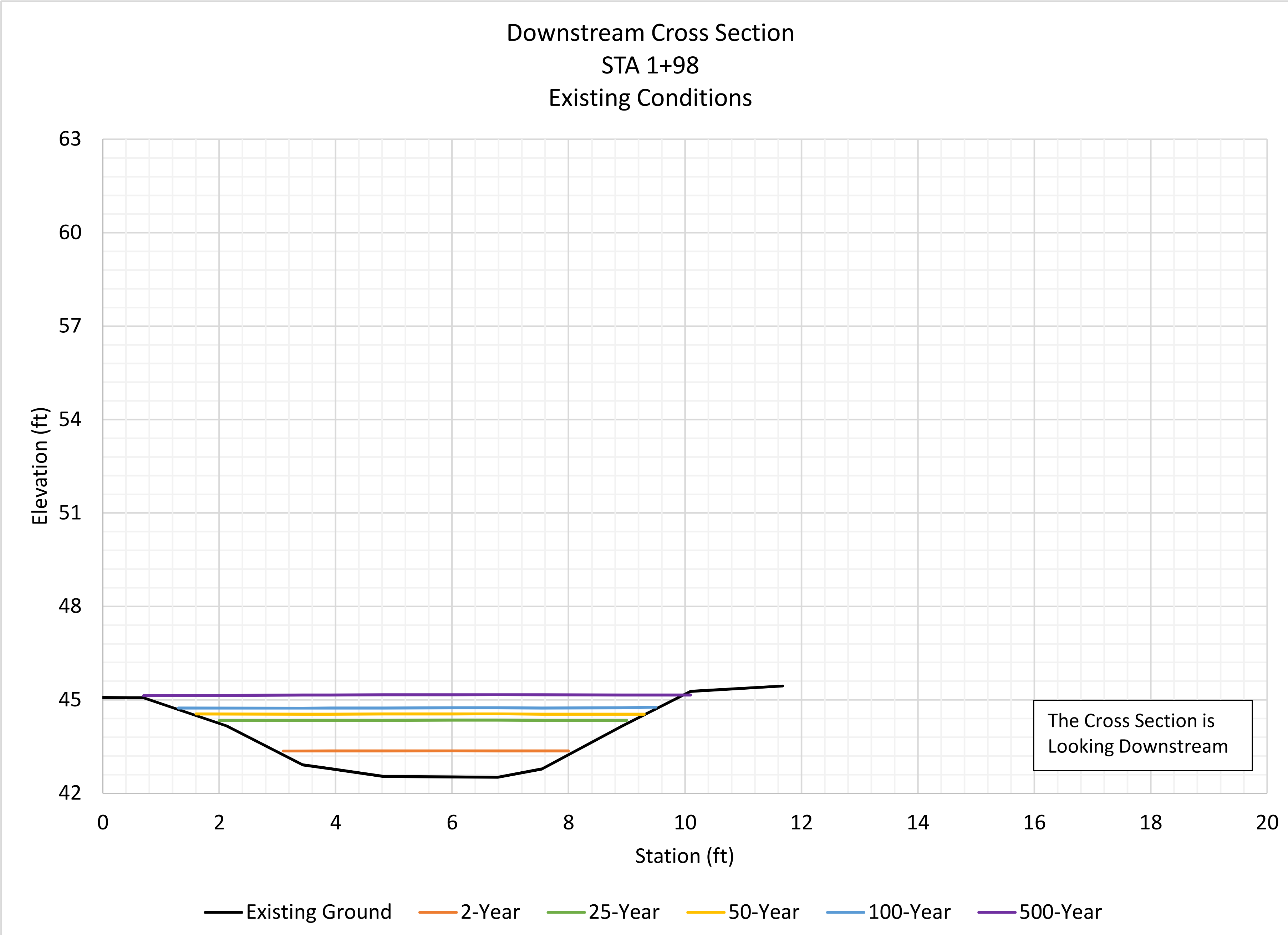
Appendix B – Stream Plan Sheets, Profile, Details

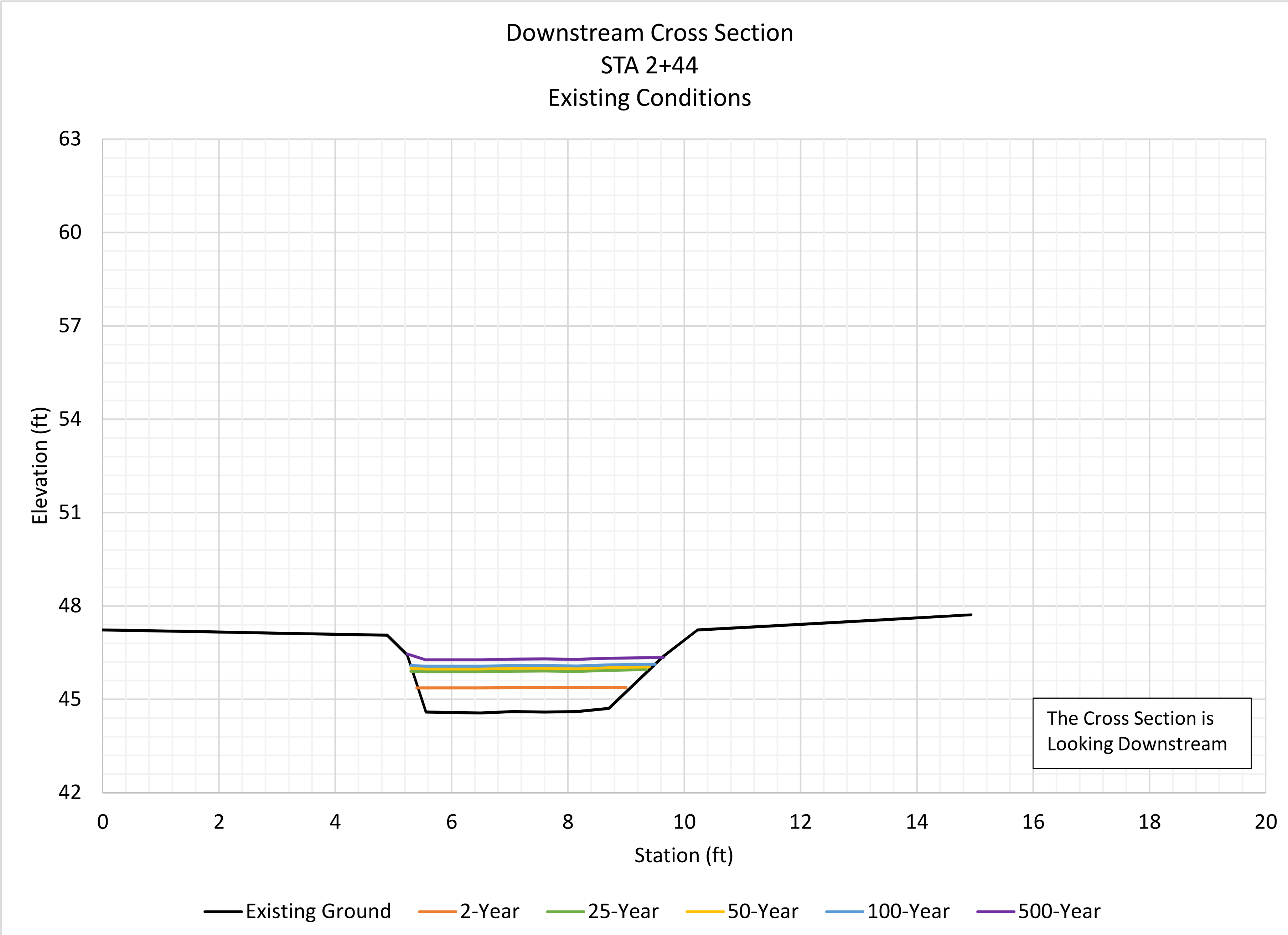
Appendix C—WDFW Future Projections for Climate-Adapted Culvert Design Printout

Appendix A – SRH-2D Model Results



Existing WSEL
Elevation (ft)
70
65
60
55
50
45
40
0+00
1+00
2+00
3+00
4+00
5+00
6+00
7+00
Station (ft)
Existing Ground
2-Year
25-Year
50-Year
100-Year
500-Year
Cross-Sections


Downstream Cross Section
STA 1+98
Existing Conditions
Elevation (ft)
63
60
57
54
51
48
45
42
0
2
4
6
8
10
12
14
16
18
20
Station (ft)
The Cross Section is Looking Downstream
Existing Ground
2-Year
25-Year
50-Year
100-Year
500-Year


Downstream Cross Section
STA 2+44
Existing Conditions
Elevation (ft)
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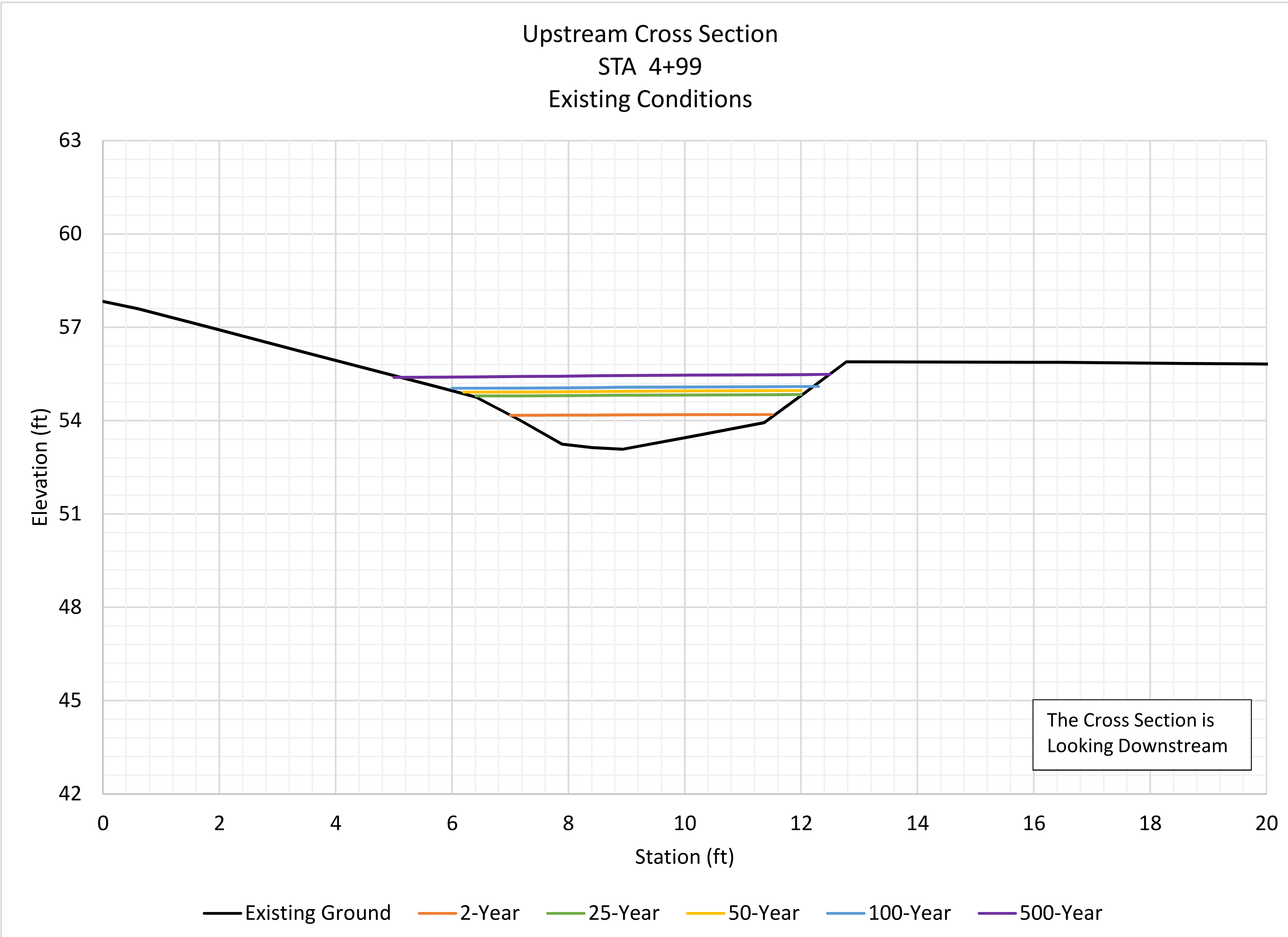
57
54
51
48
45
42
0
2
4
6
8
10
12
14
16
18
20
Station (ft)
The Cross Section is Looking Downstream
Existing Ground
2-Year
25-Year
50-Year
100-Year
500-Year



Upstream Cross Section
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Existing Conditions
Elevation (ft)
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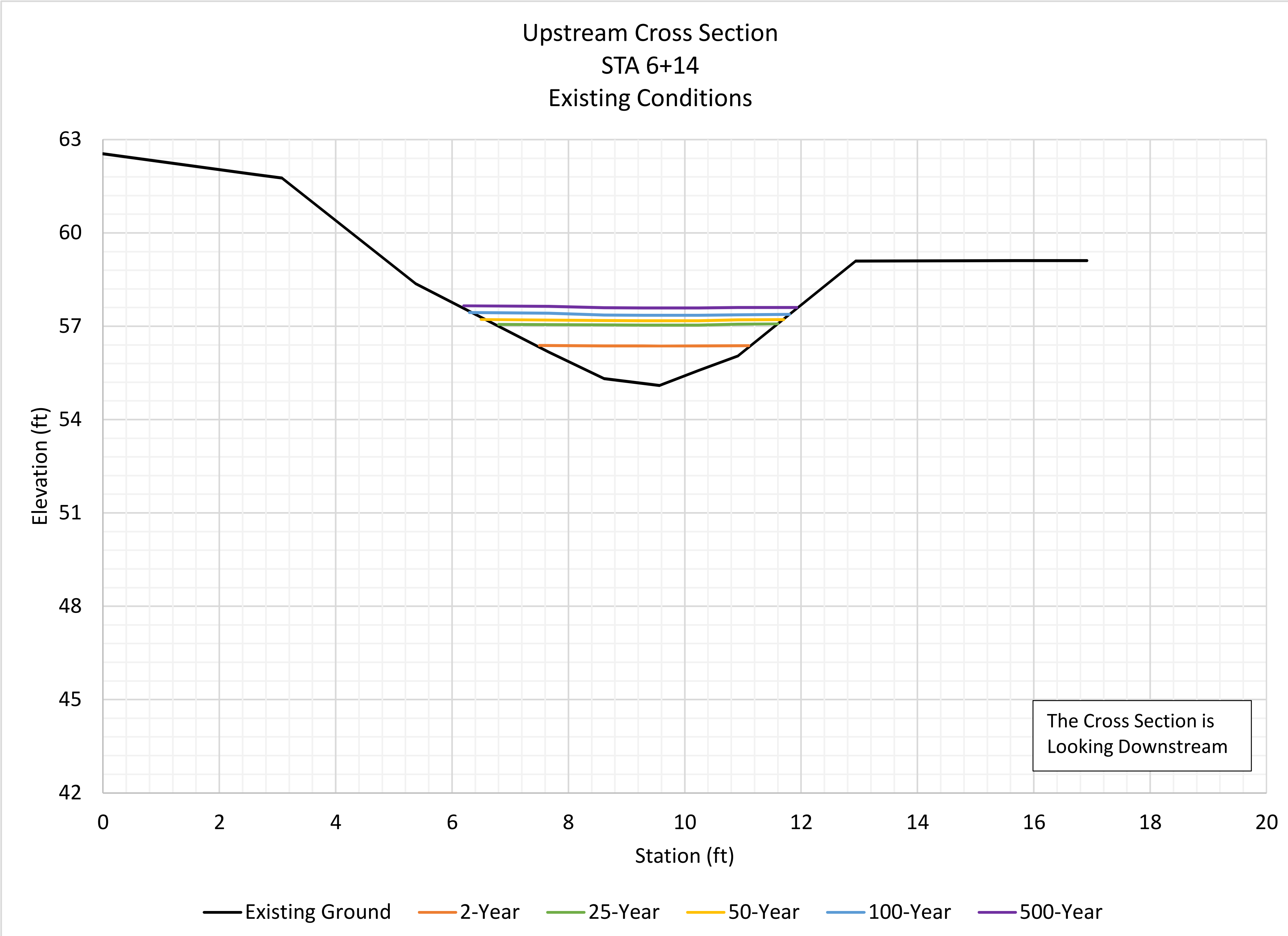
54
51
48
45
42
0
2
4
6
8
10
12
14
16
18
20
Station (ft)
The Cross Section is
Looking Downstream
Existing Ground
2-Year
25-Year
50-Year
100-Year
500-Year



Upstream Cross Section
STA 6+14
Existing Conditions
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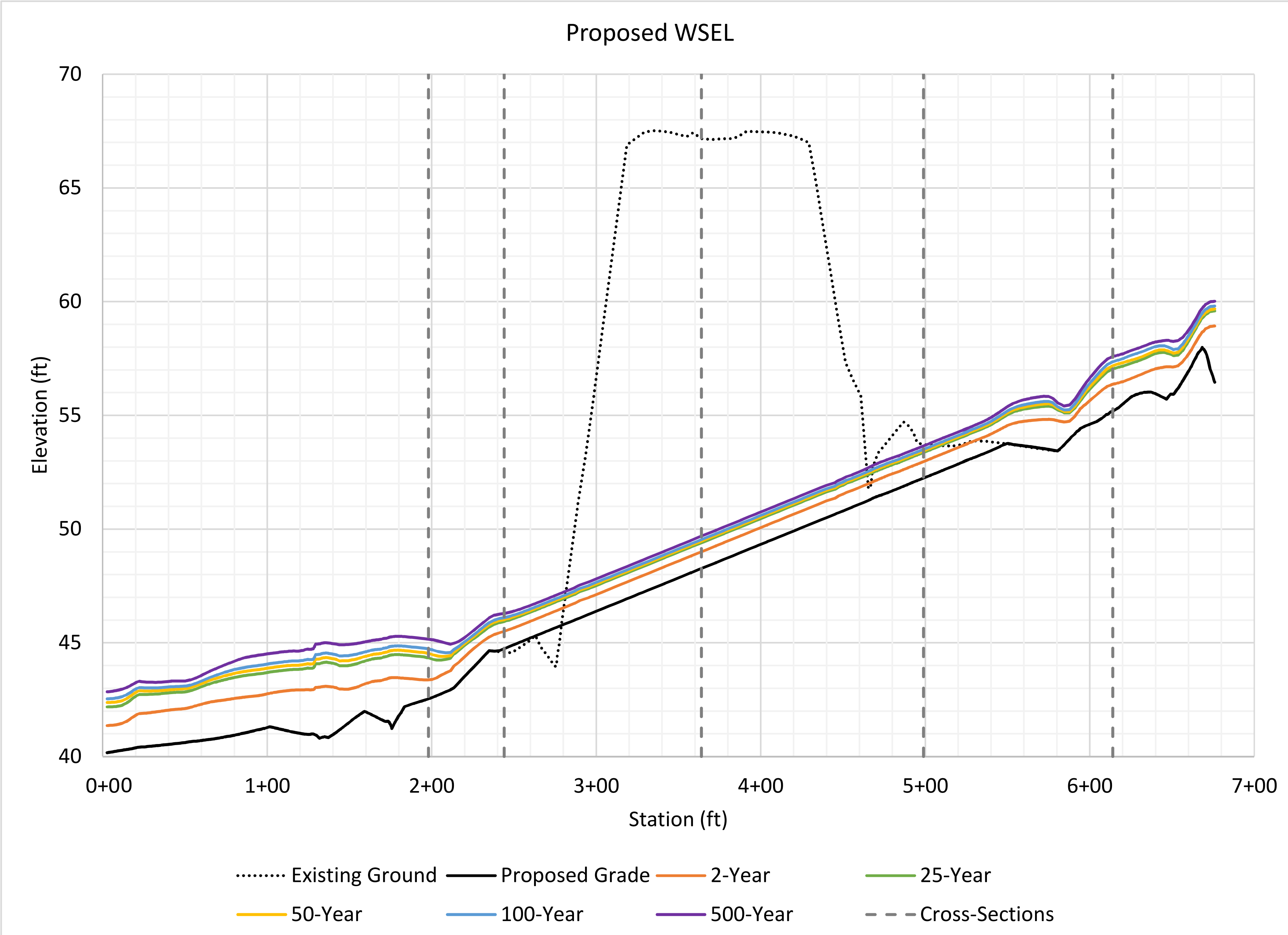
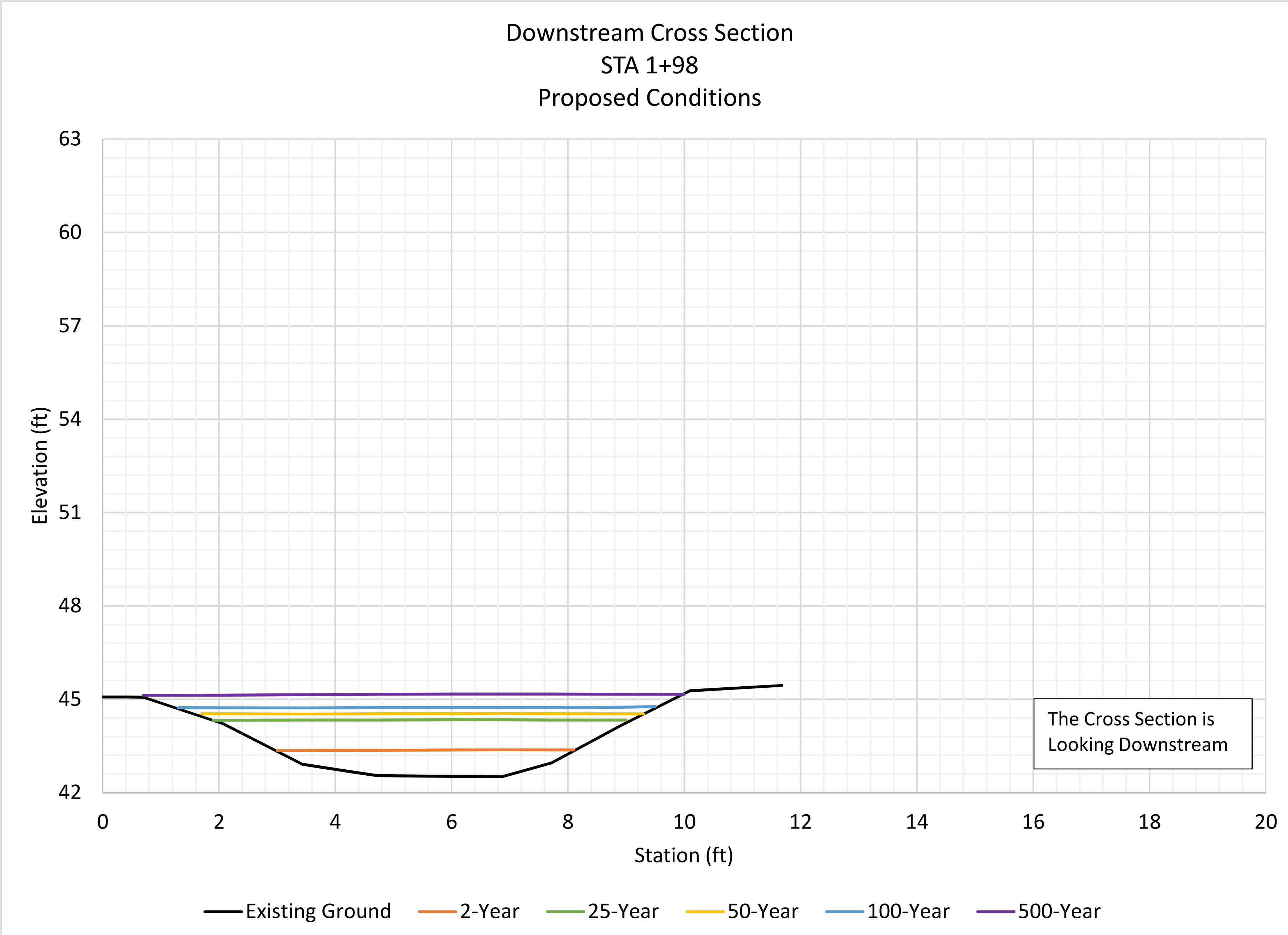
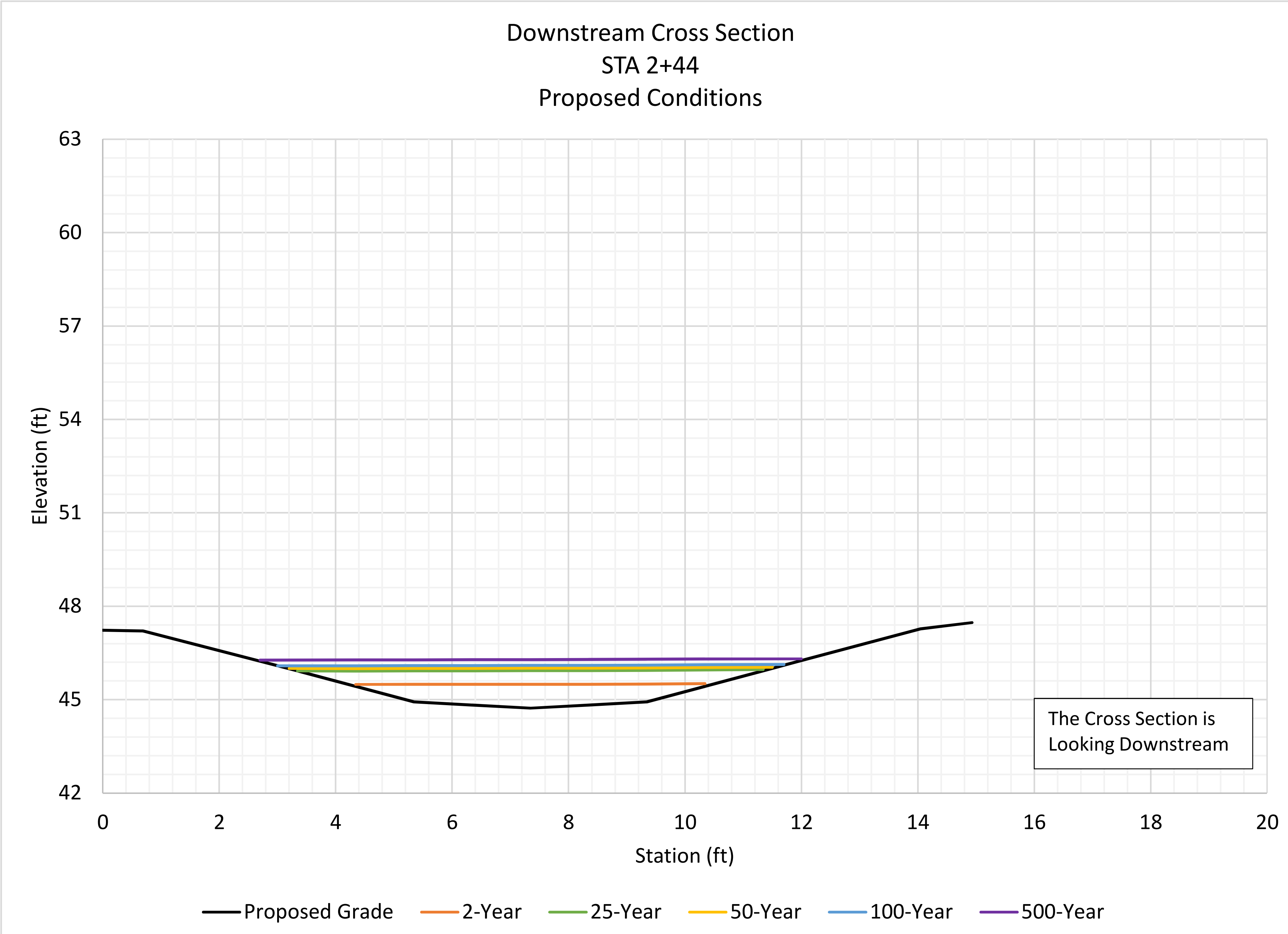
60
57
54
51
48
45
42
Elevation (ft)
0
2
4
6
8
10
12
14
16
18
20
Station (ft)
The Cross Section is Looking Downstream
Existing Ground
2-Year
25-Year
50-Year
100-Year
500-Year



Proposed WSEL
70
65
60
55
50
45
40
Elevation (ft)
0+00
1+00
2+00
3+00
4+00
5+00
6+00
7+00
Station (ft)
Existing Ground
Proposed Grade
2-Year
25-Year
50-Year
100-Year
500-Year
Cross-Sections



Downstream Cross Section
STA 1+98
Proposed Conditions
Elevation (ft)
63
60
57
54
51
48
45
42
0
2
4
6
8
10
12
14
16
18
20
Station (ft)
The Cross Section is Looking Downstream
Existing Ground
2-Year
25-Year
50-Year
100-Year
500-Year


Downstream Cross Section
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Proposed Conditions
Elevation (ft)
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60
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48
45
42
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2
4
6
8
10
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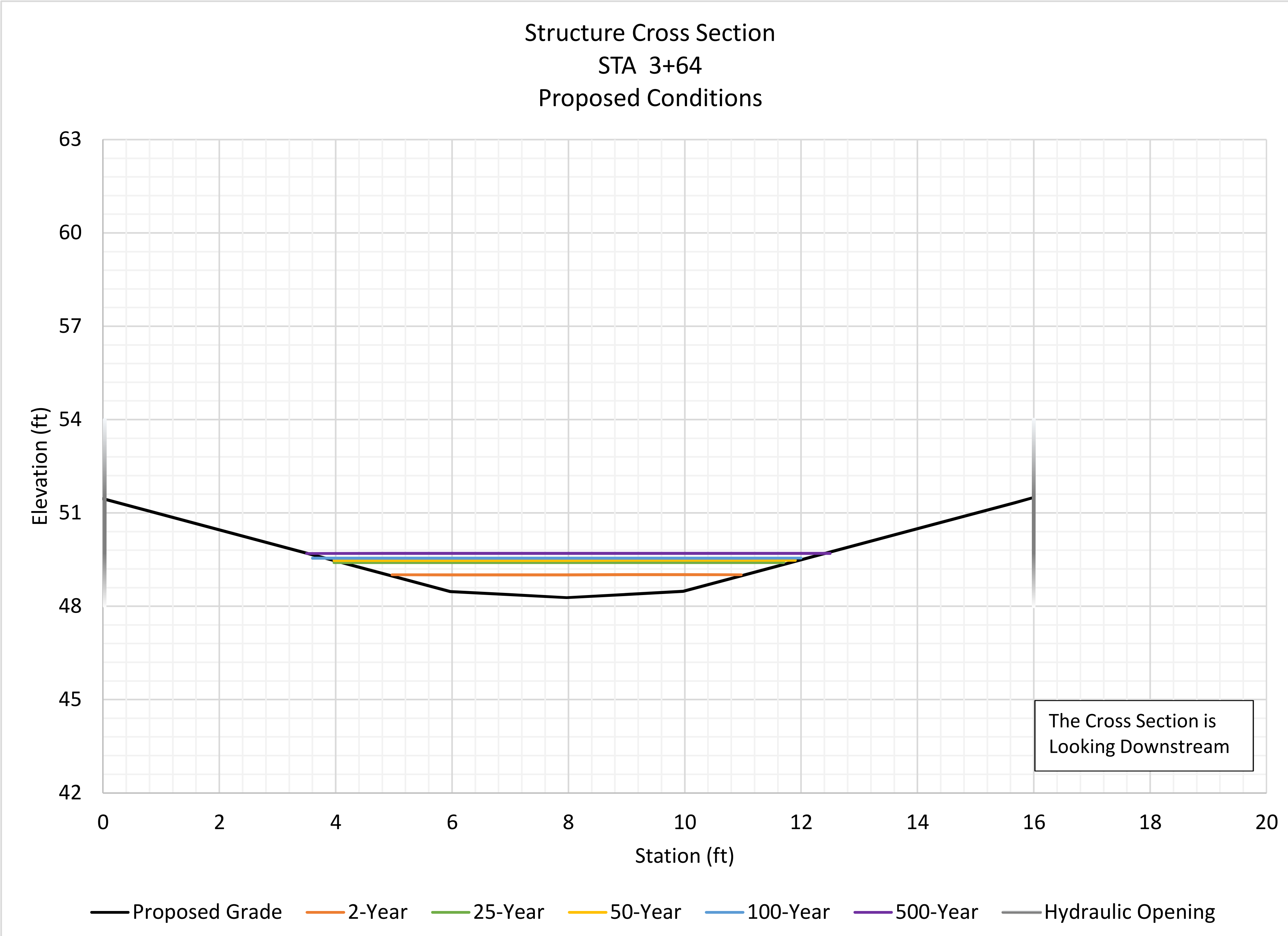
20
Station (ft)
The Cross Section is Looking Downstream
Proposed Grade
2-Year
25-Year
50-Year
100-Year
500-Year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8
10
12
14
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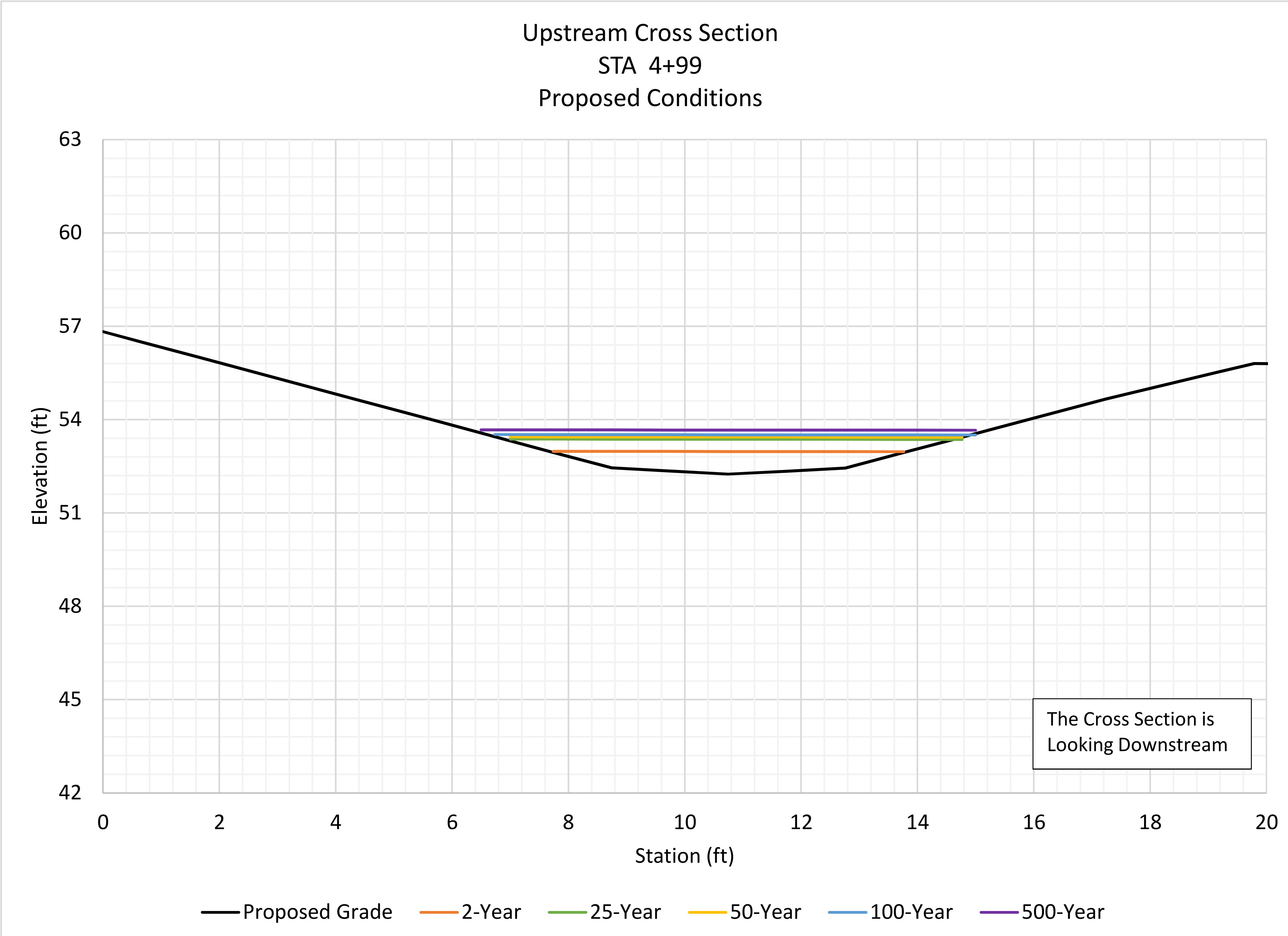
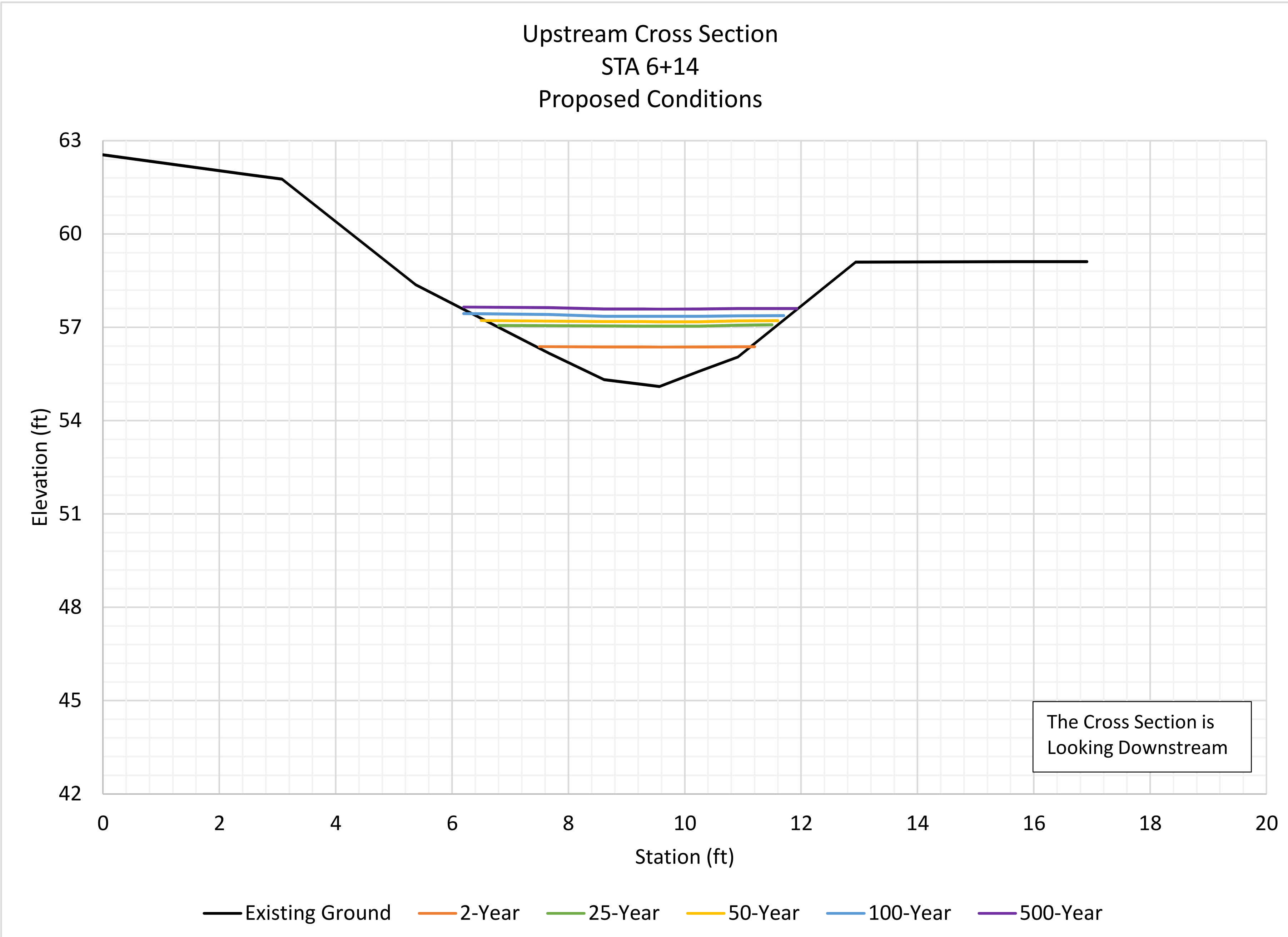
20
Station (ft)
The Cross Section is Looking Downstream
Proposed Grade
2-Year
25-Year
50-Year
100-Year
500-Year
Hydraulic Opening



Upstream Cross Section
STA 4+99
Proposed Conditions
Elevation (ft)
63
60
57
54
51
48
45
42
0
2
4
6
8
10
12
14
16
18
20
Station (ft)
The Cross Section is
Looking Downstream
Proposed Grade
2-Year
25-Year
50-Year
100-Year
500-Year


Upstream Cross Section
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Proposed Conditions
Elevation (ft)
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60
57
54
51
48
45
42
0
2
4
6
8
10
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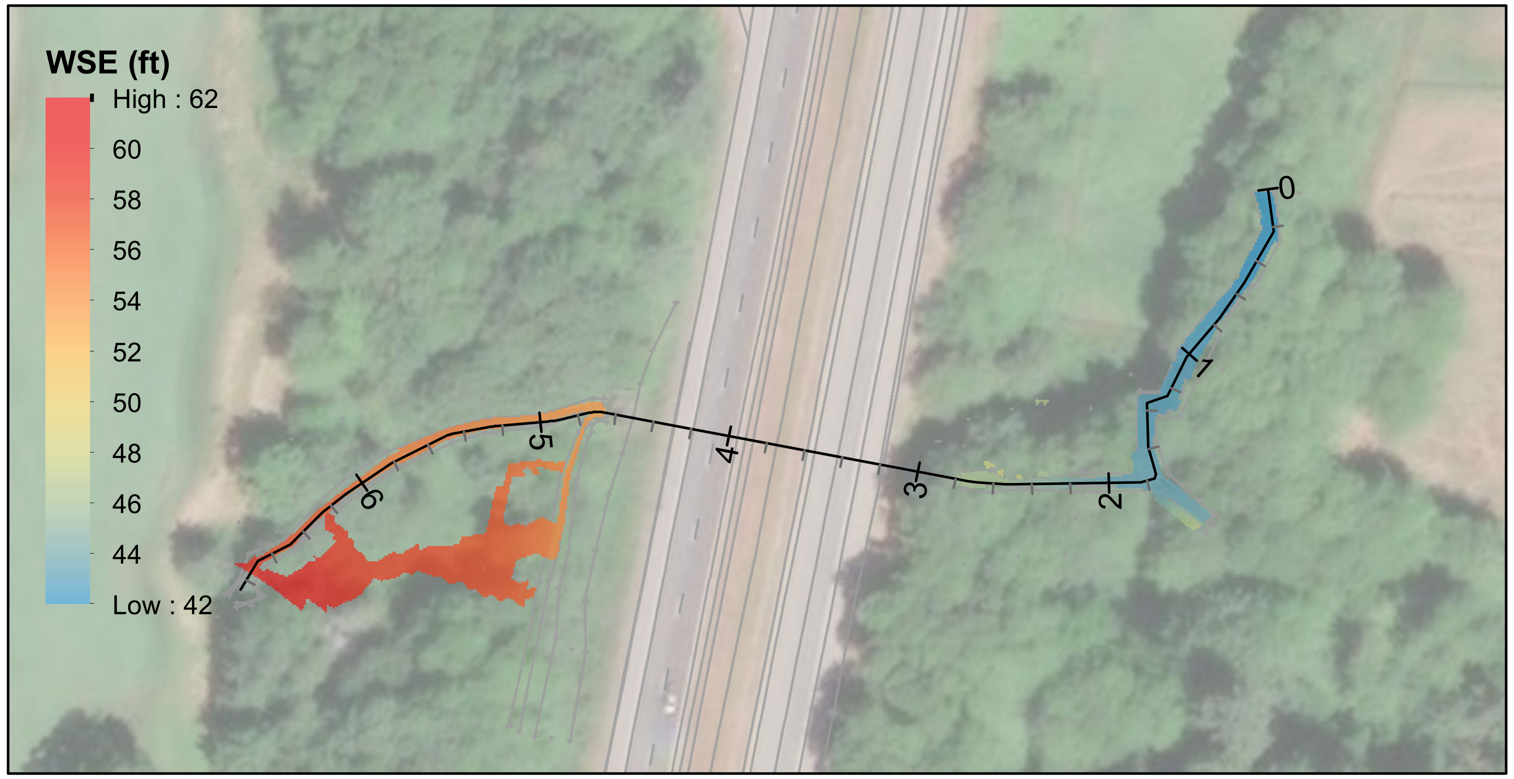
14
16
18
20
Station (ft)
The Cross Section is Looking Downstream
Existing Ground
2-Year
25-Year
50-Year
100-Year
500-Year



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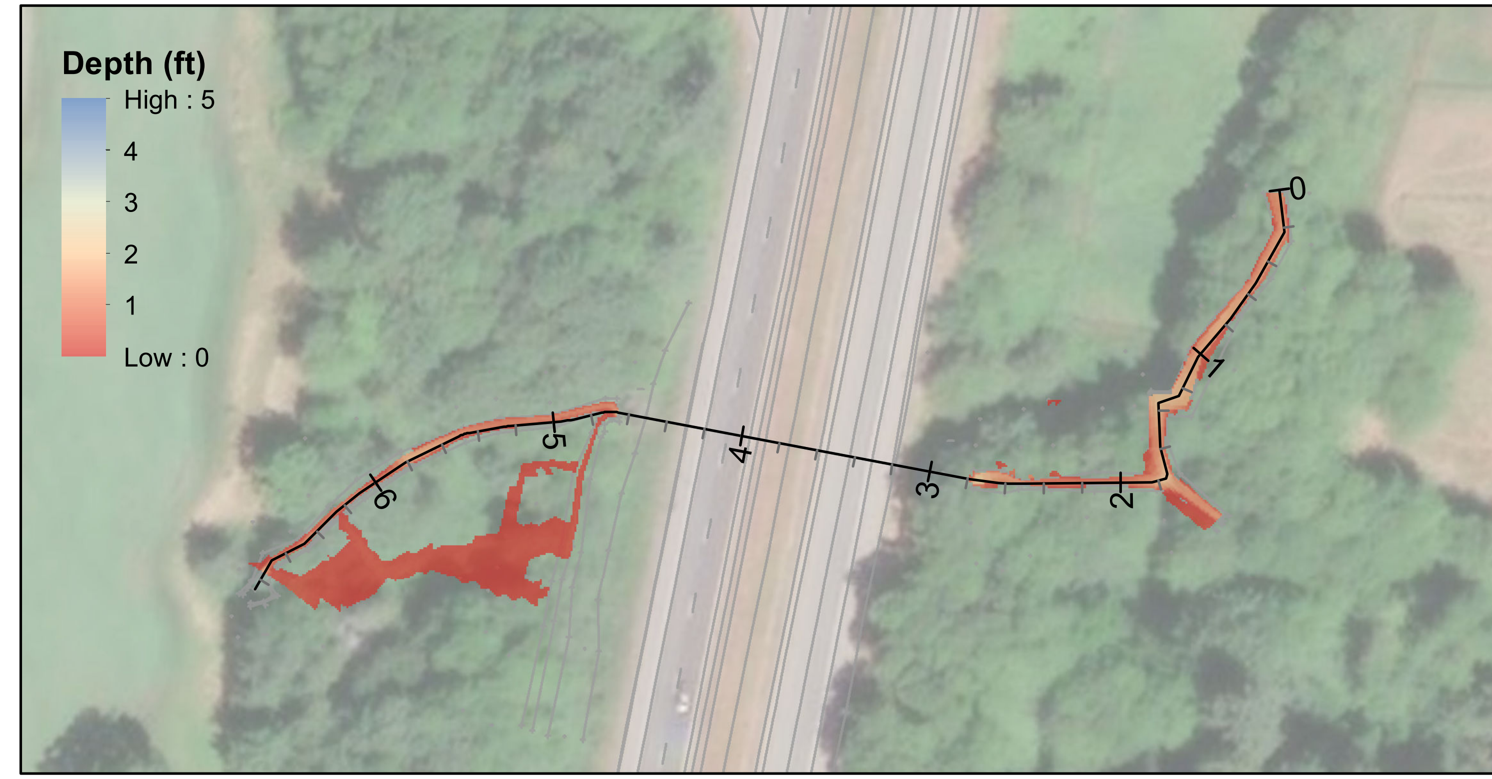
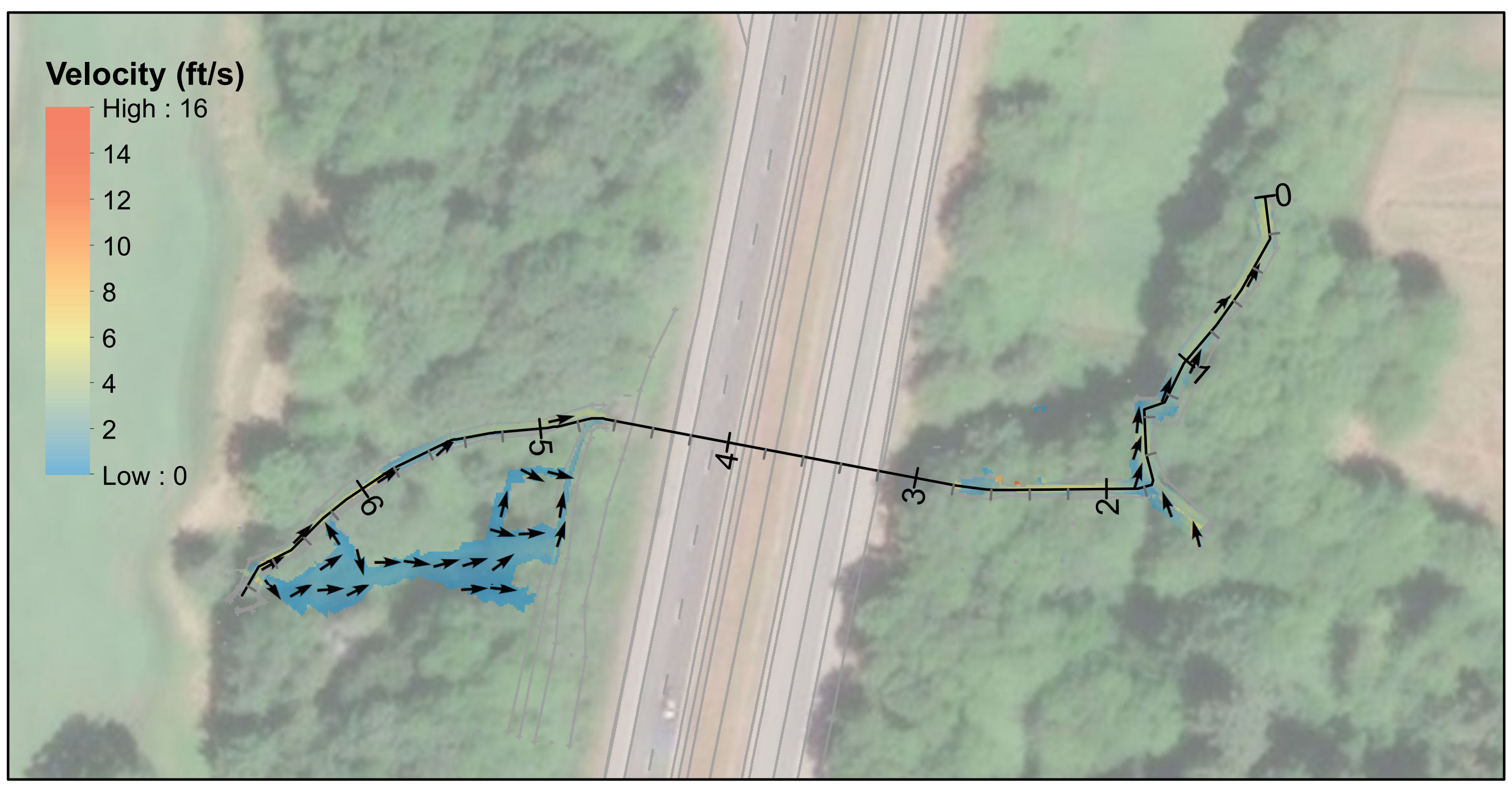


DEPTH



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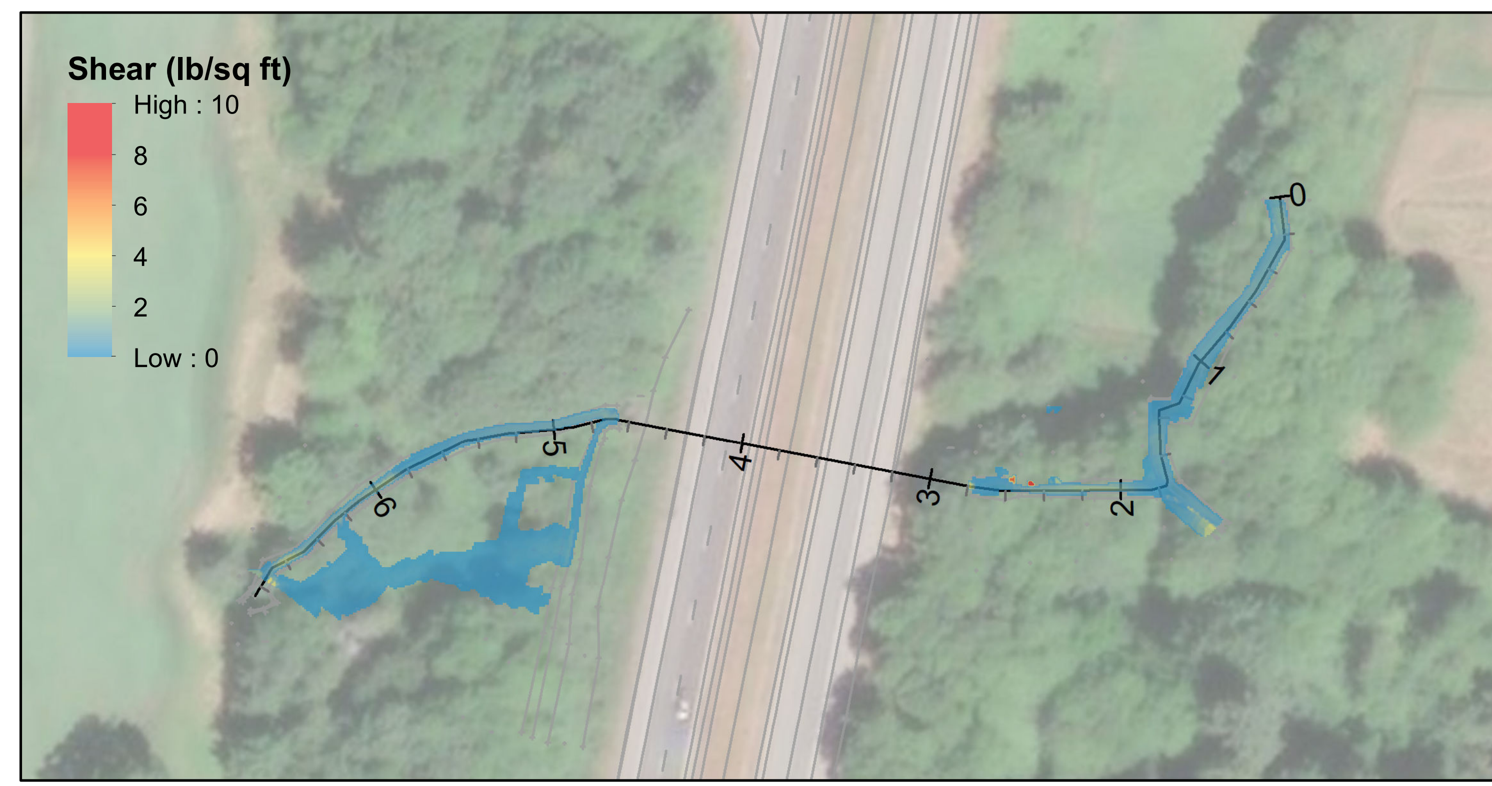


SHEAR

N

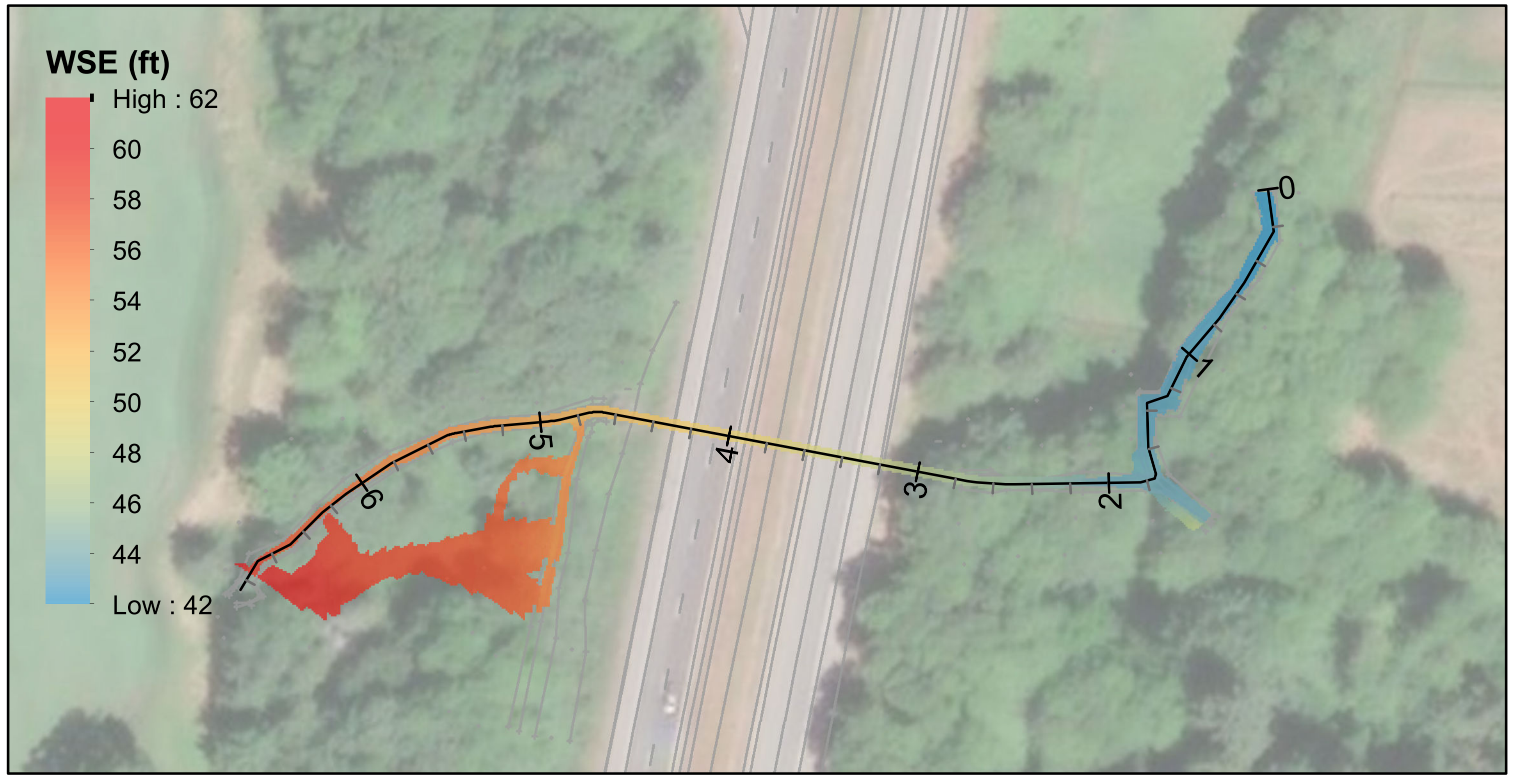
0 50 100 Feet

HDR

Washington State Department of Transportation

EXISTING CONDITIONS - 2 YEAR EVENT

US 101 UNNAMED TRIBUTARY TO SKOOKUM CREEK
MP 354.01



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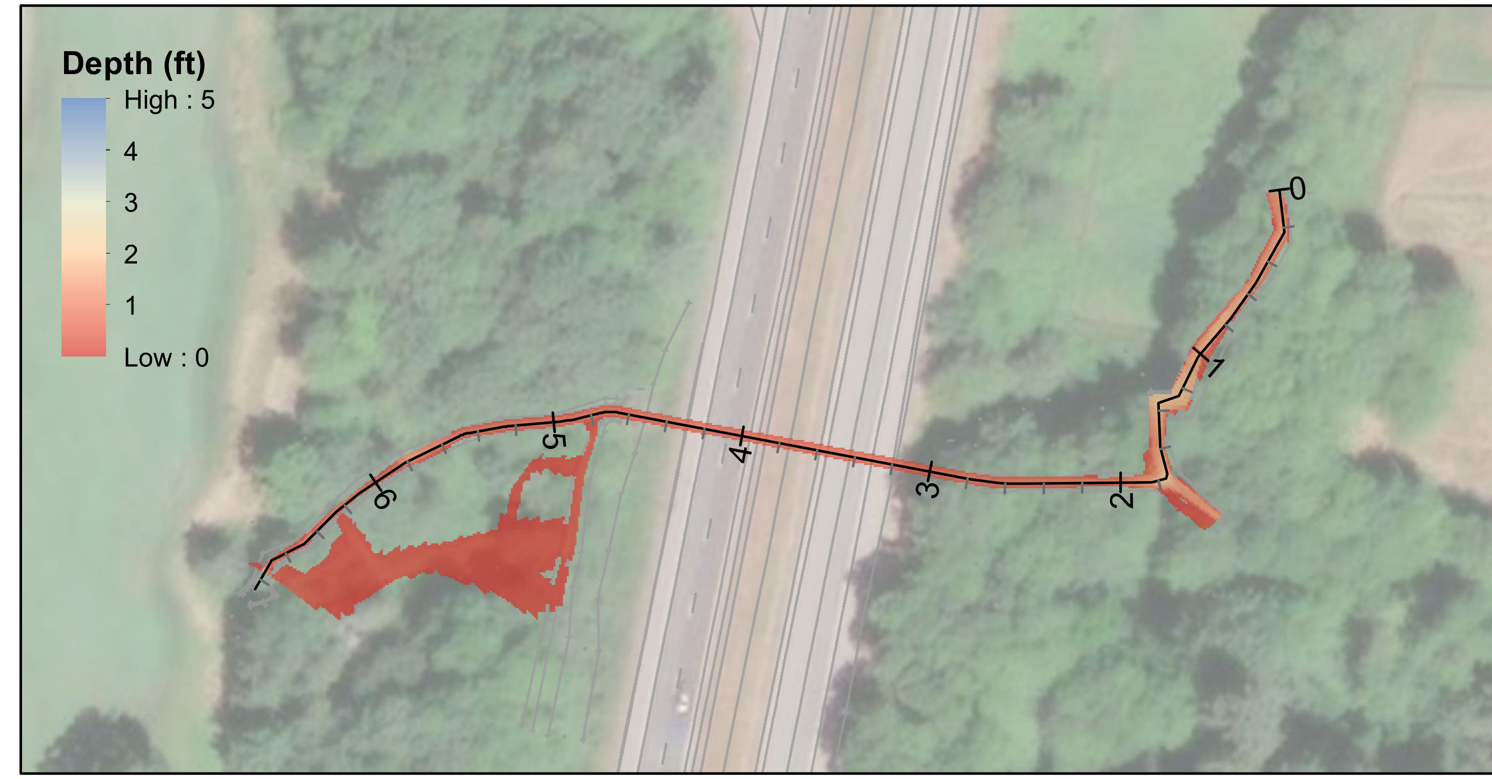

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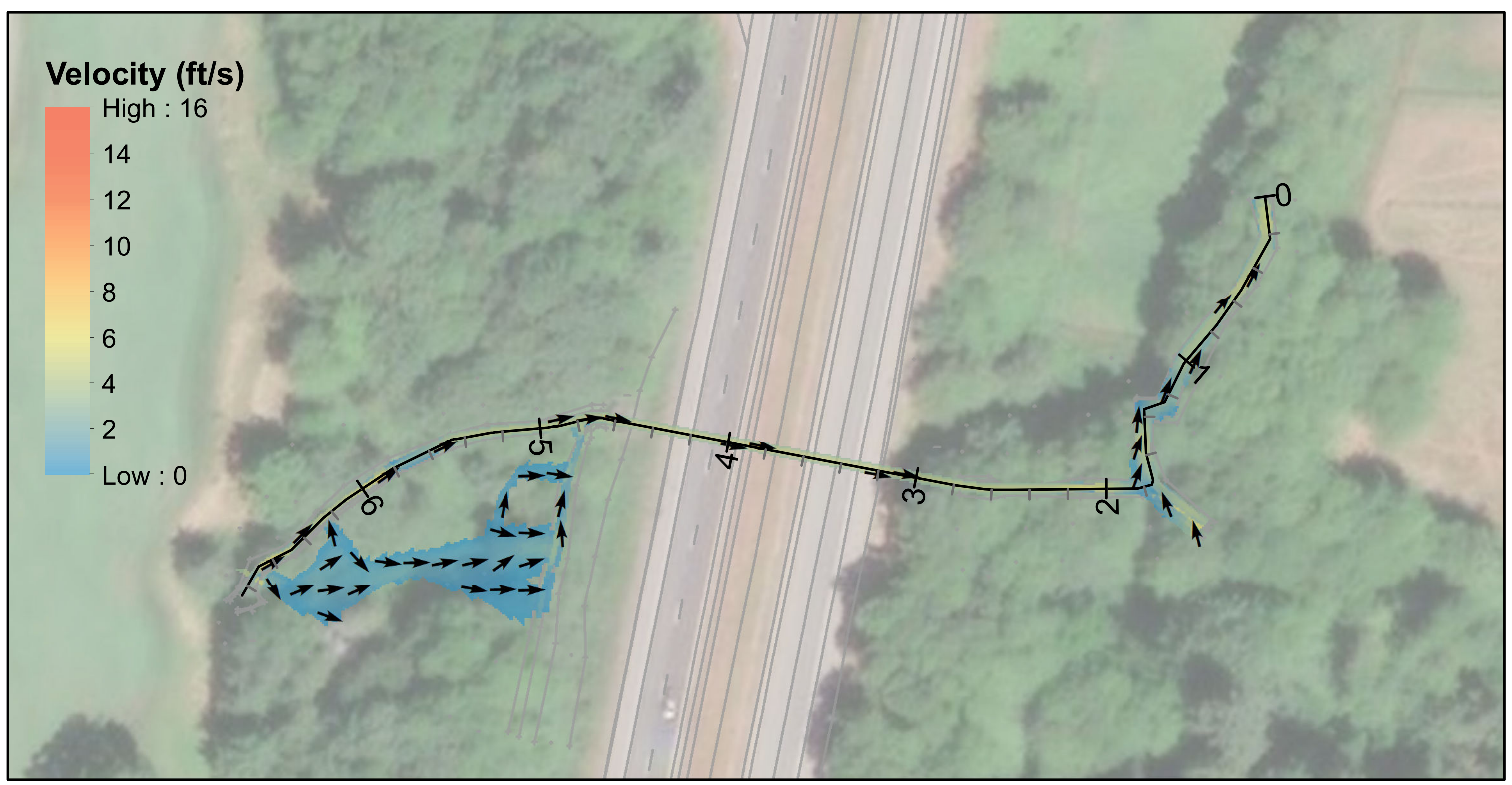

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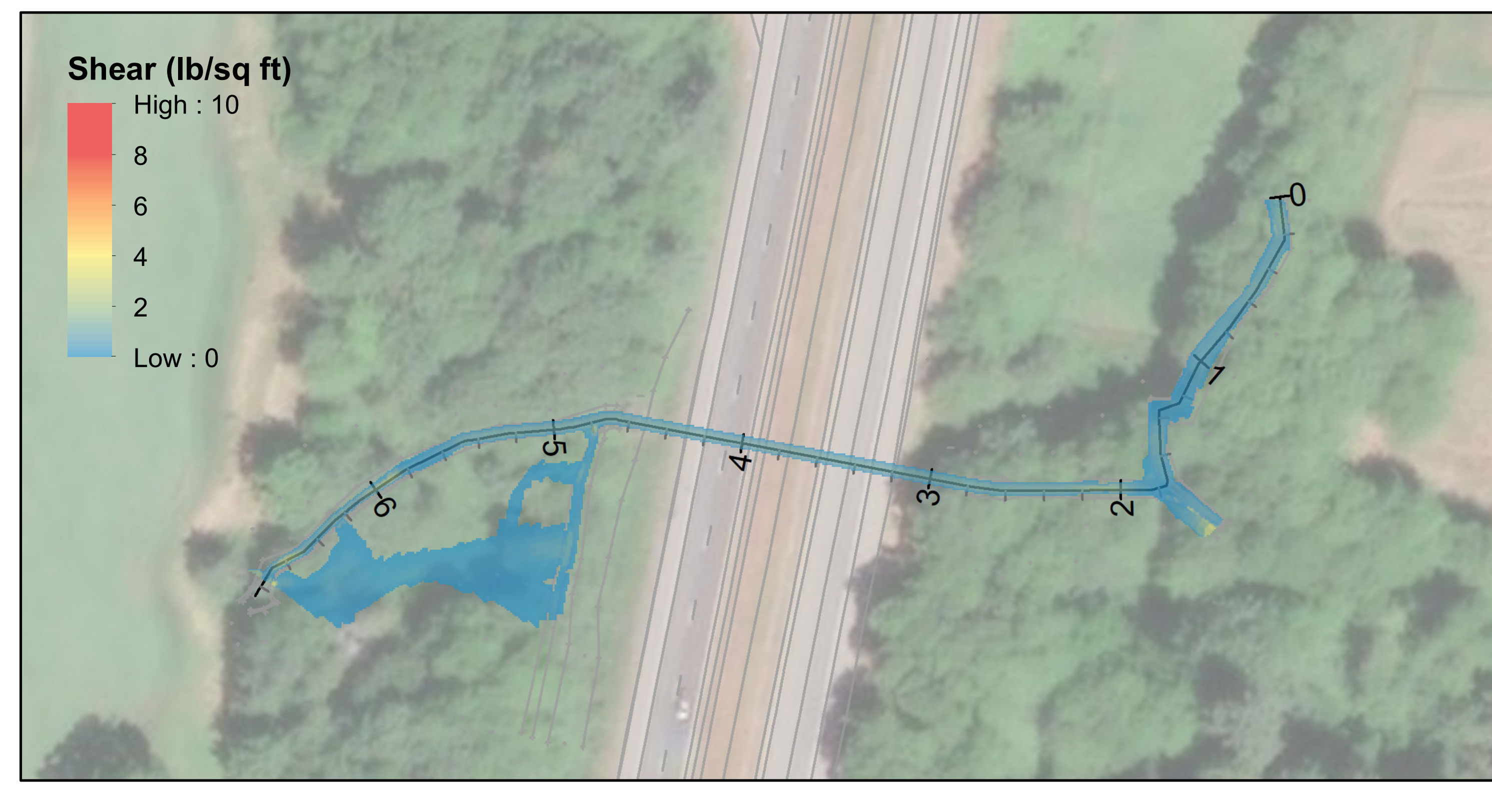

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Washington State Department of Transportation

PROPOSED CONDITIONS - 2 YEAR EVENT

US 101 UNNAMED TRIBUTARY TO SKOOKUM CREEK
MP 354.01

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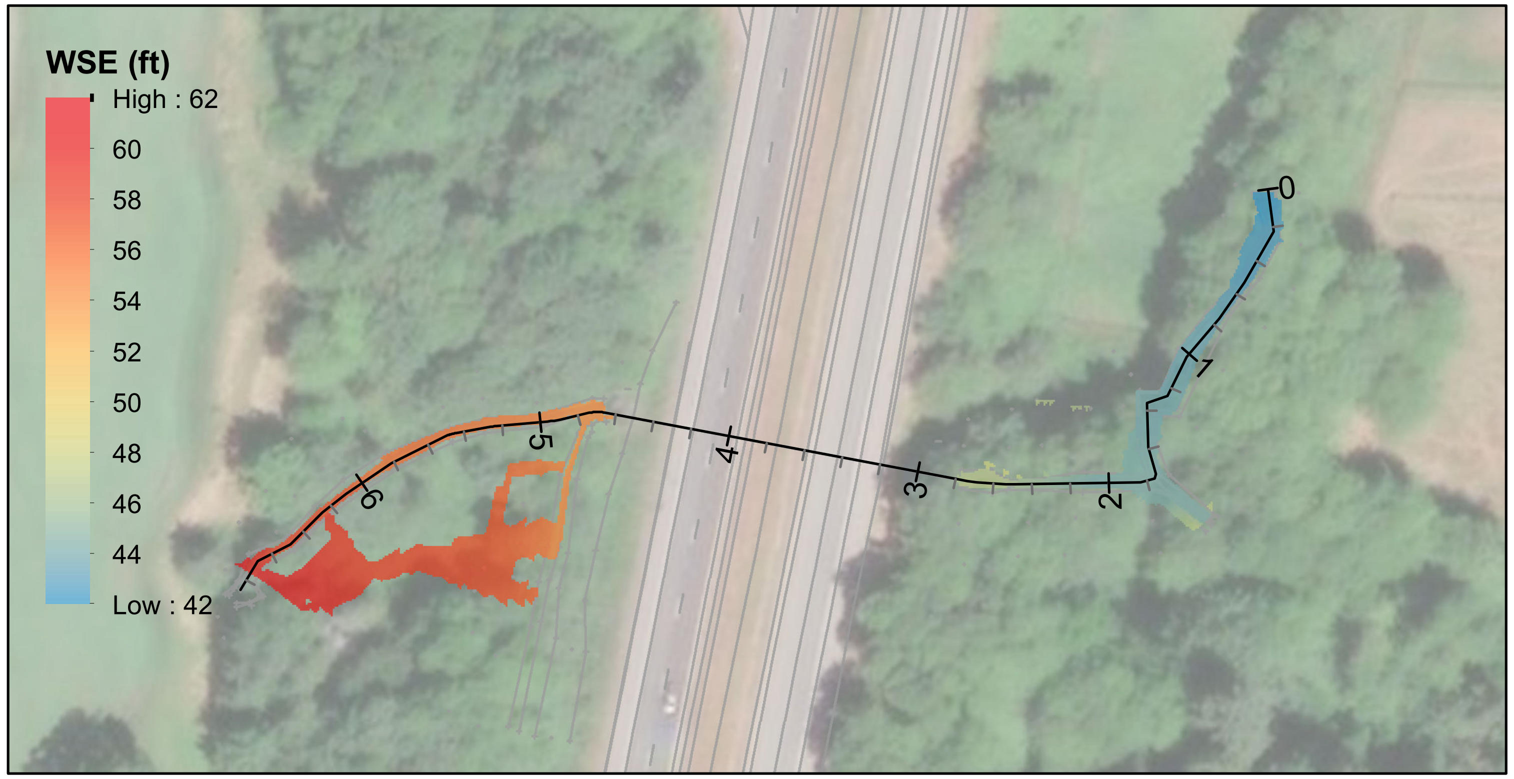

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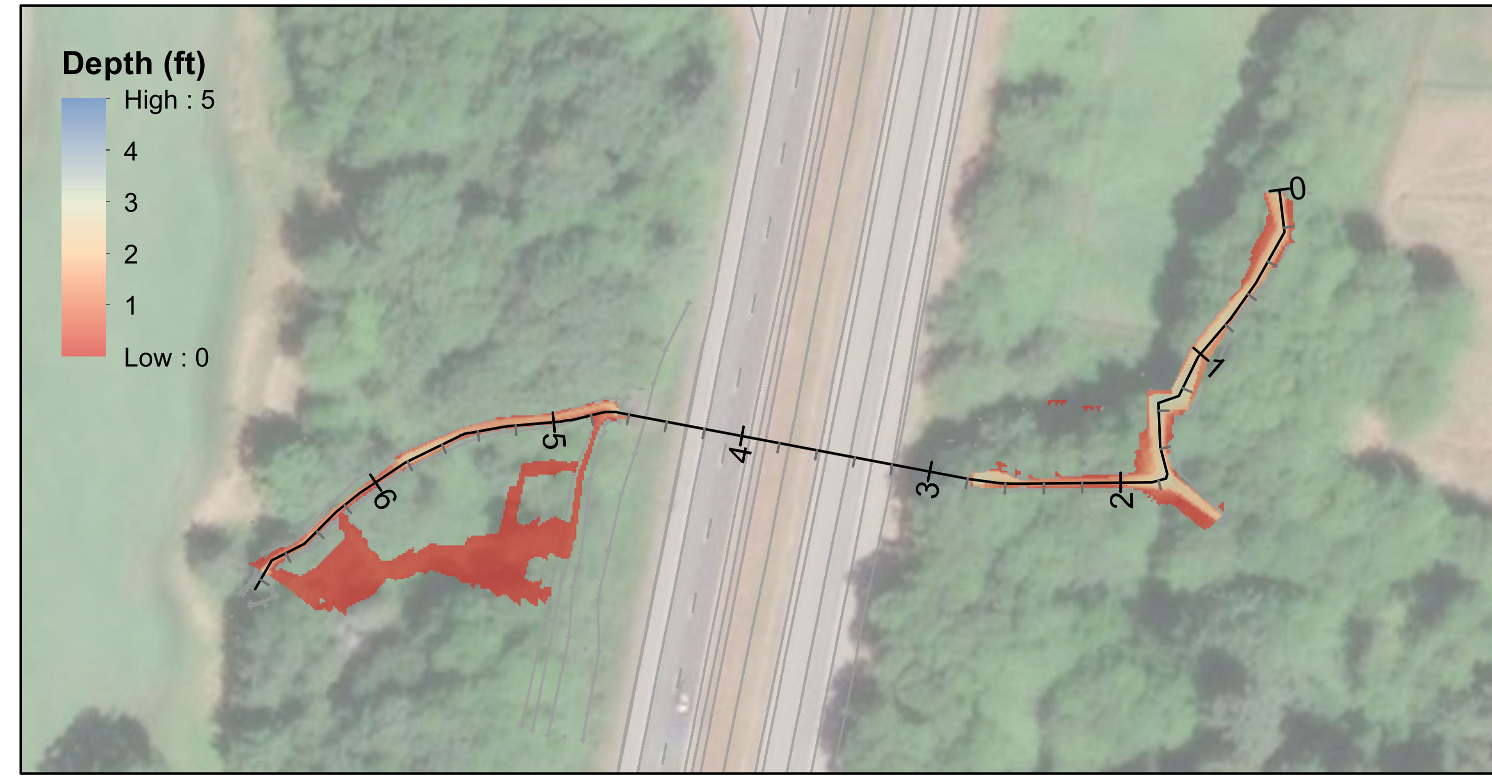

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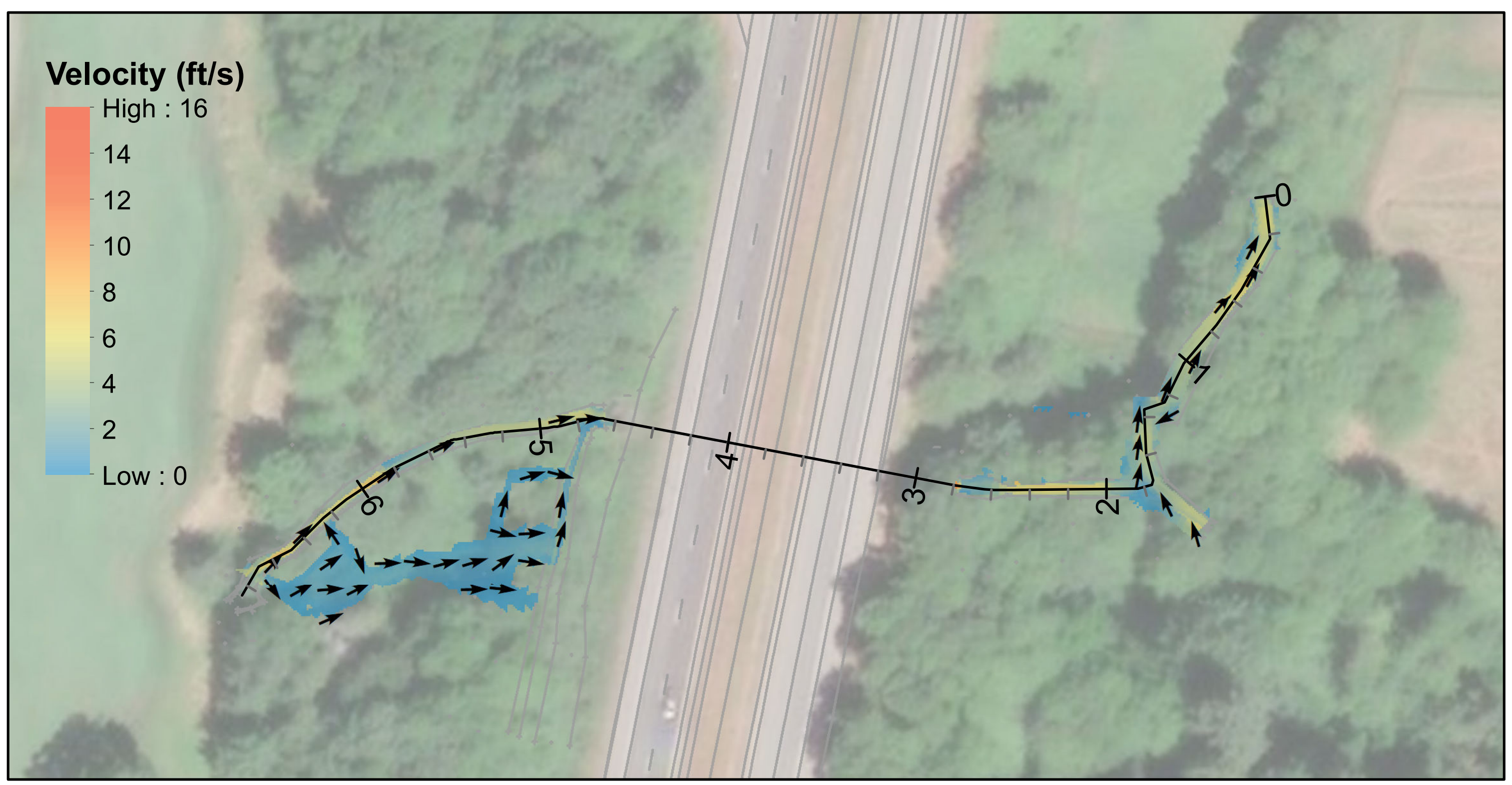

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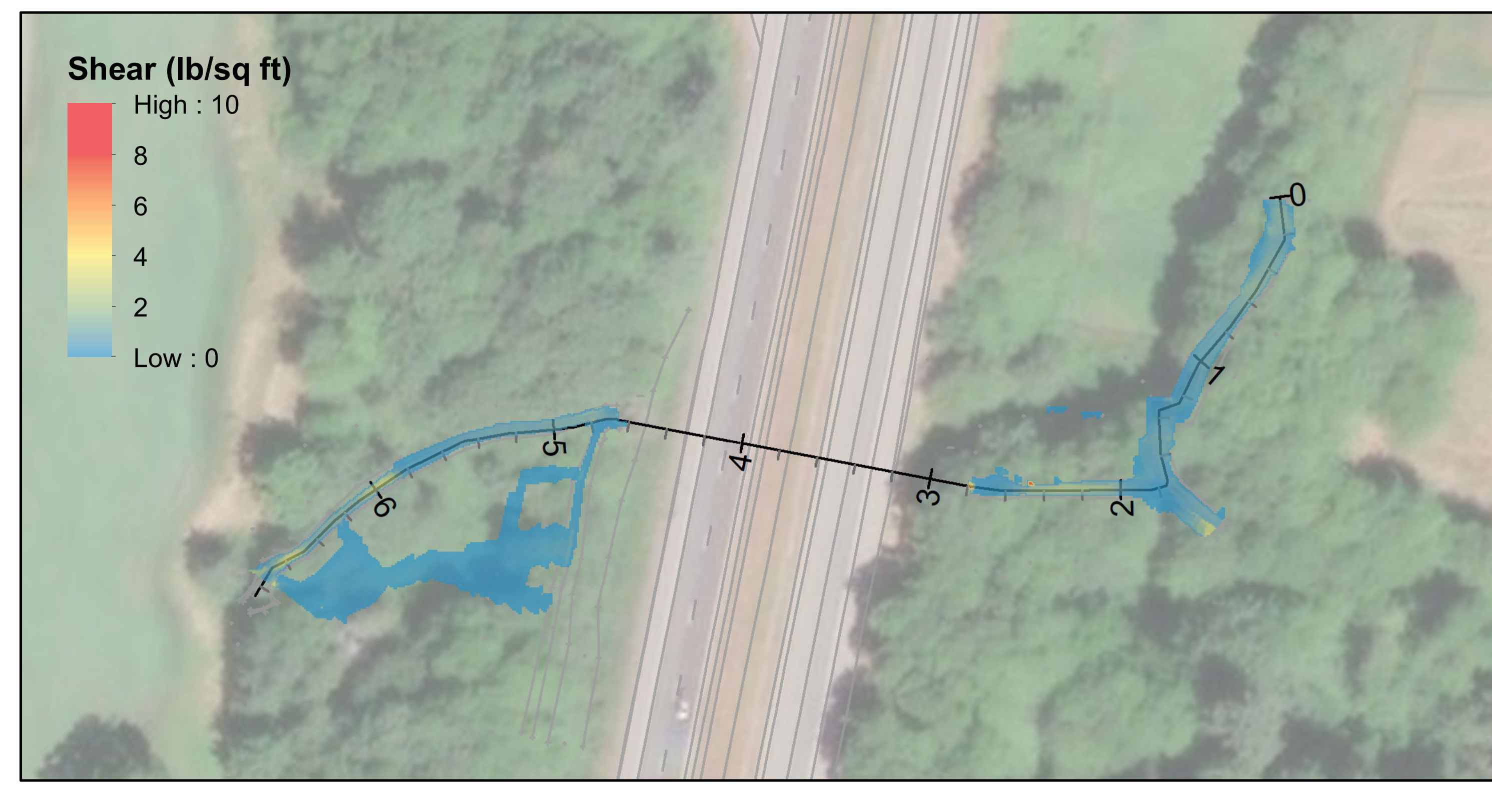

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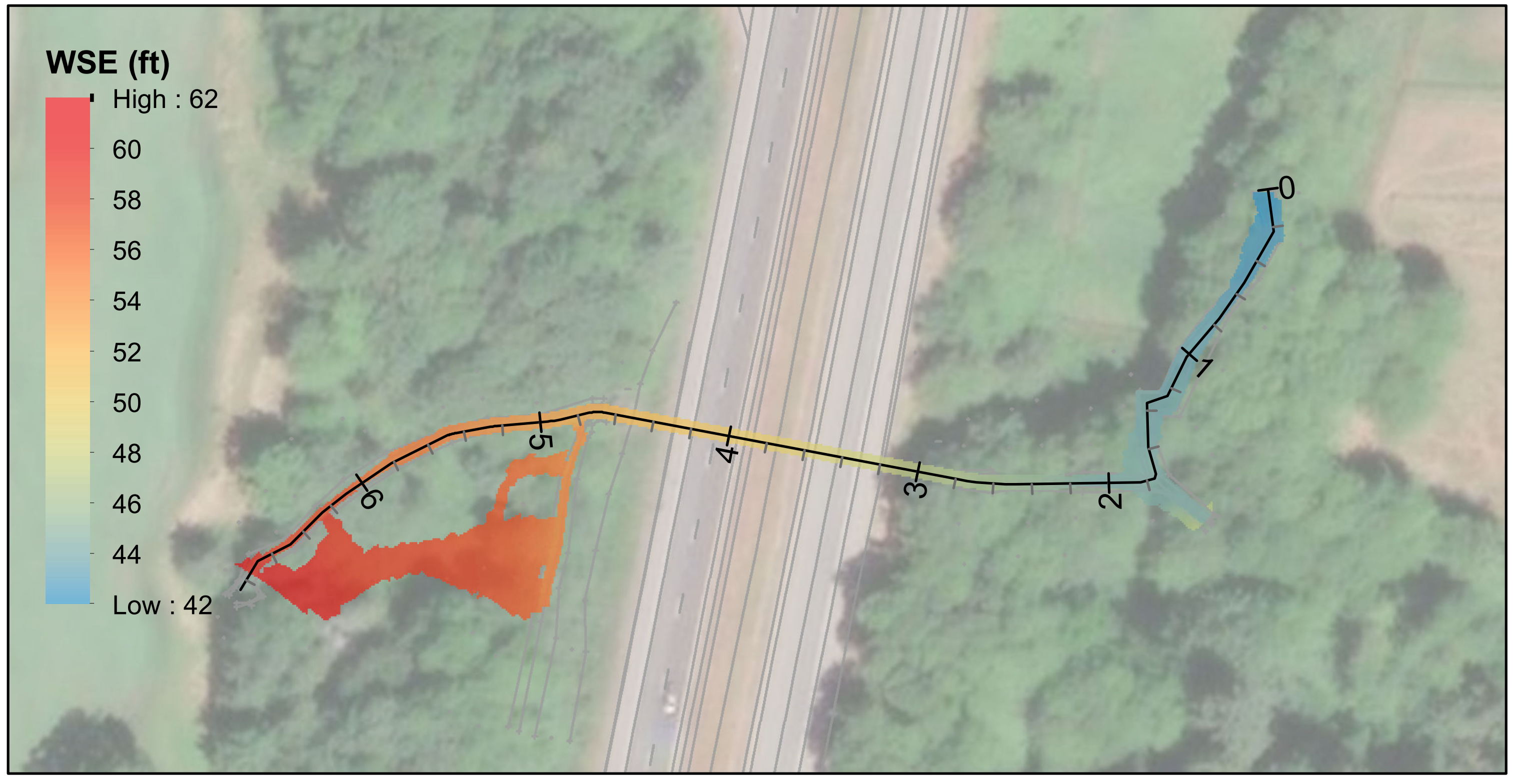
Washington State Department of Transportation

EXISTING CONDITIONS - 25 YEAR EVENT

US 101 UNNAMED TRIBUTARY TO SKOOKUM CREEK
MP 354.01



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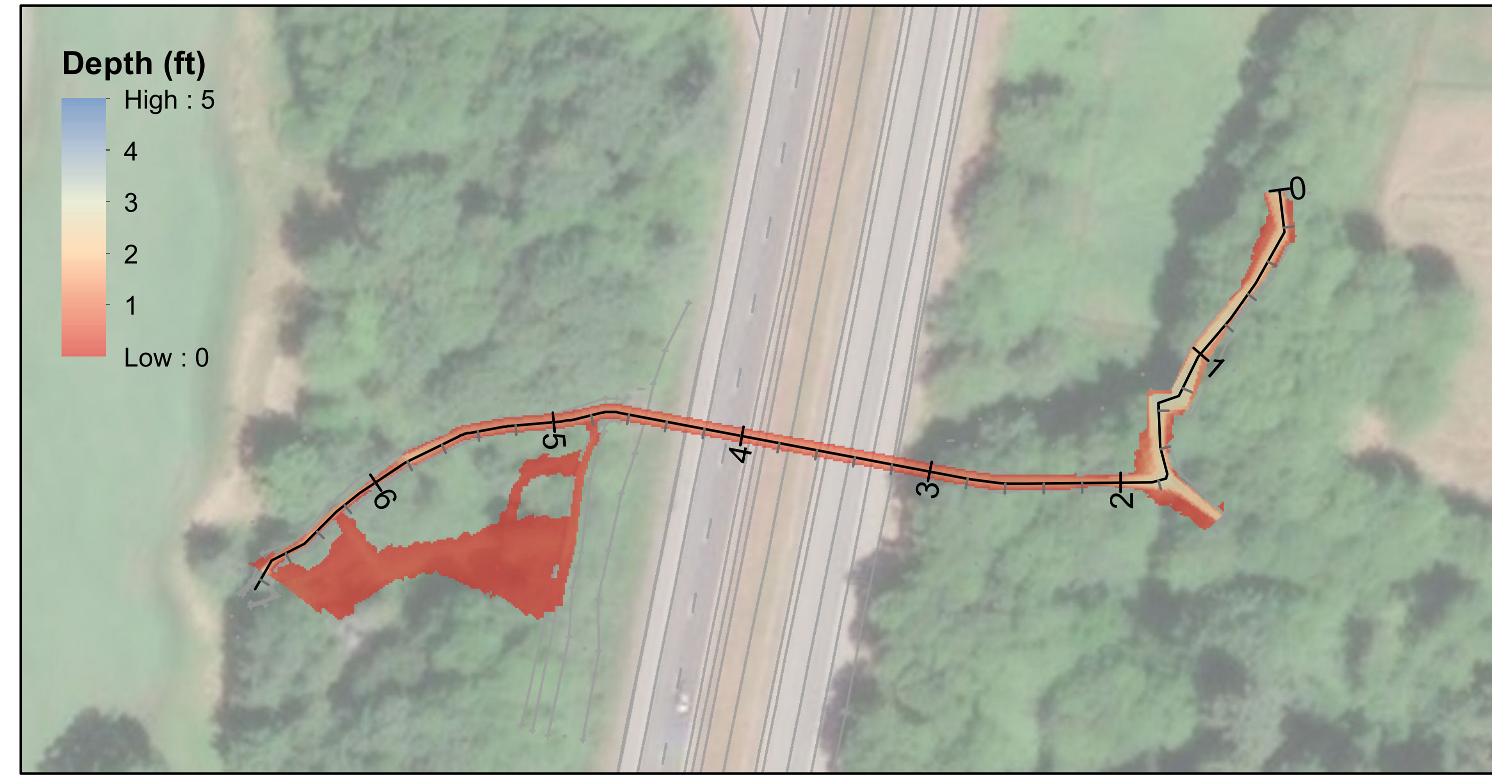

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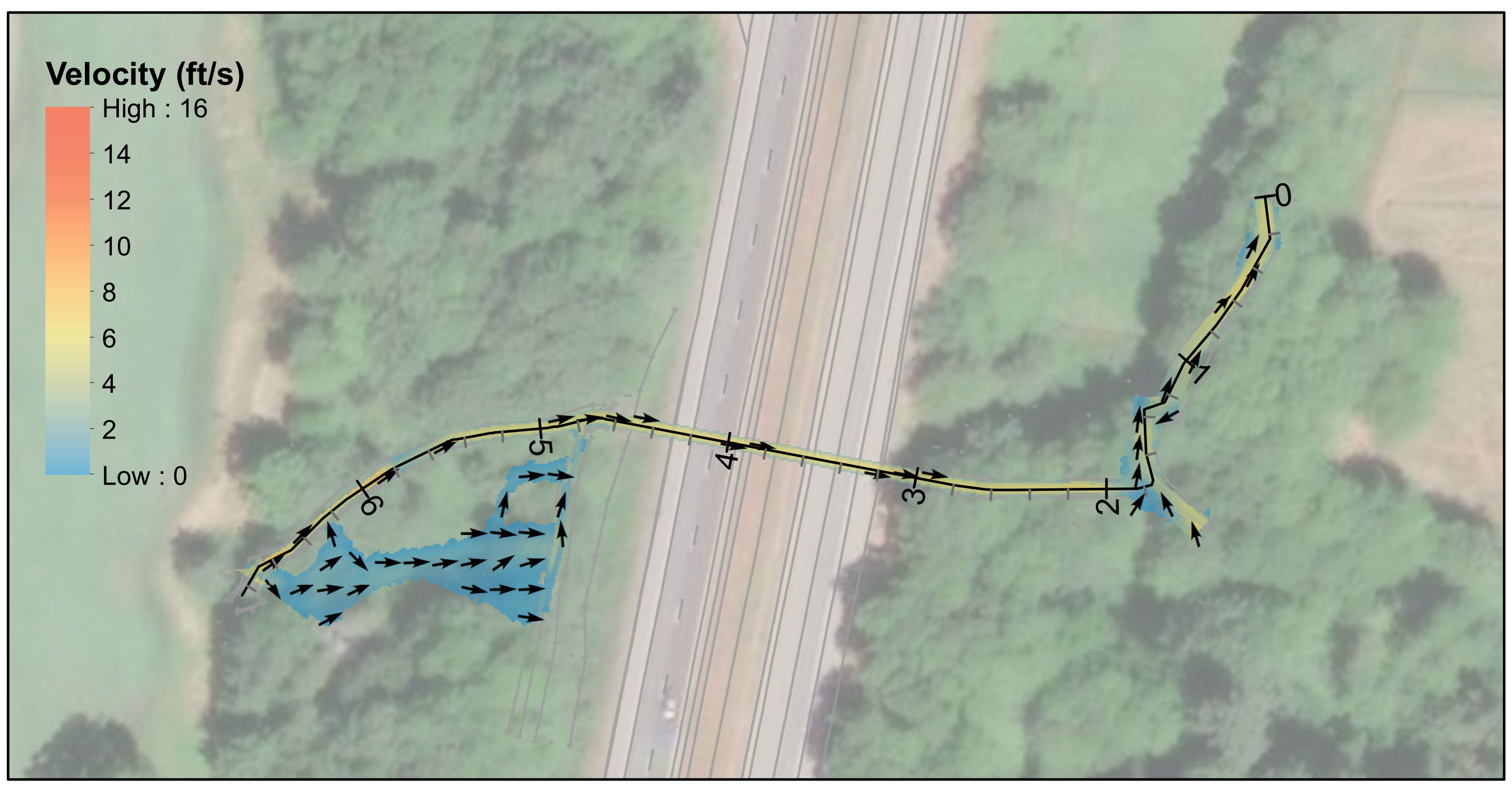
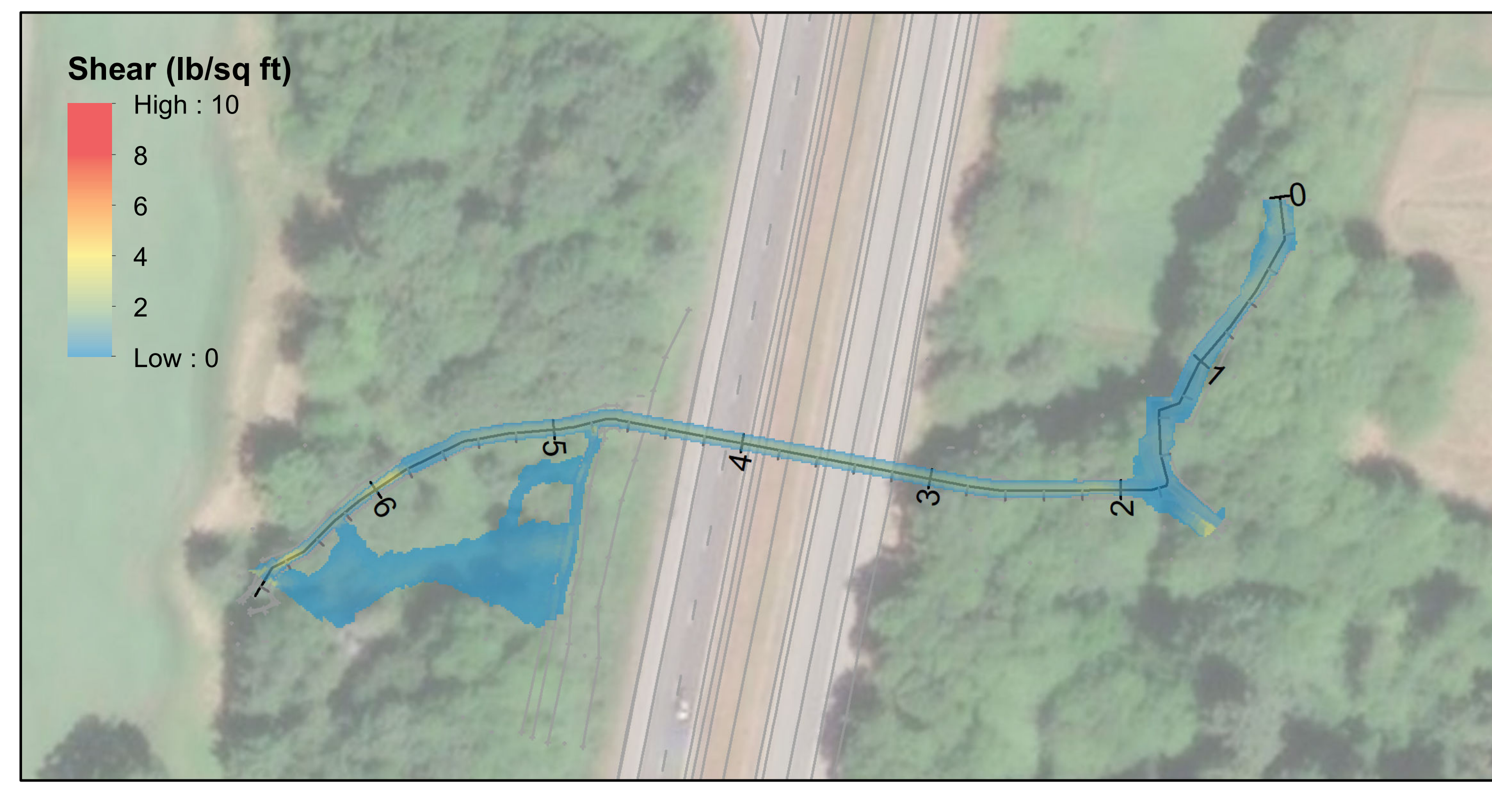


VELOCITY



SHEAR

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0 50 100 Feet

Washington State Department of Transportation

PROPOSED CONDITIONS - 25 YEAR EVENT

US 101 UNNAMED TRIBUTARY TO SKOOKUM CREEK
MP 354.01

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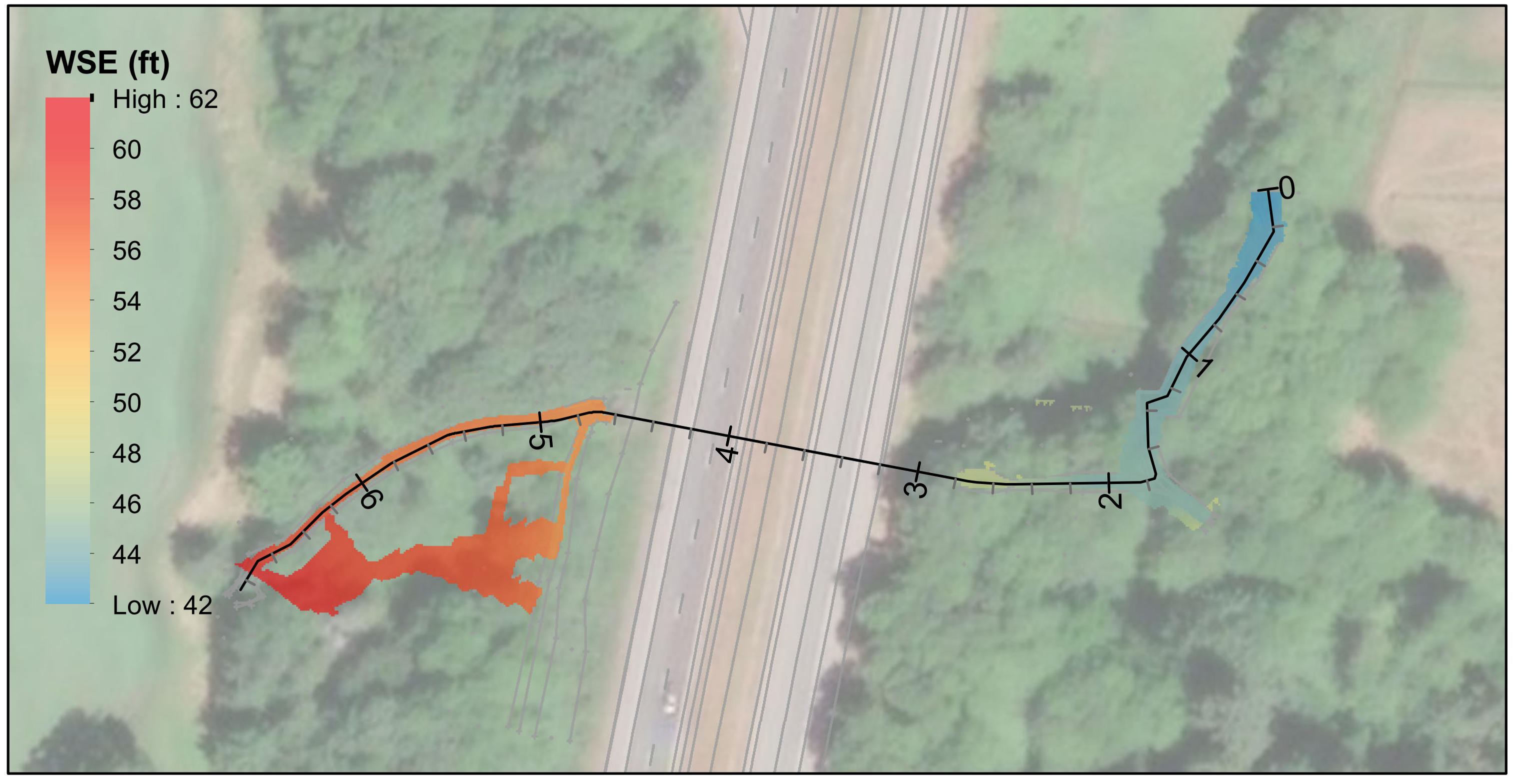

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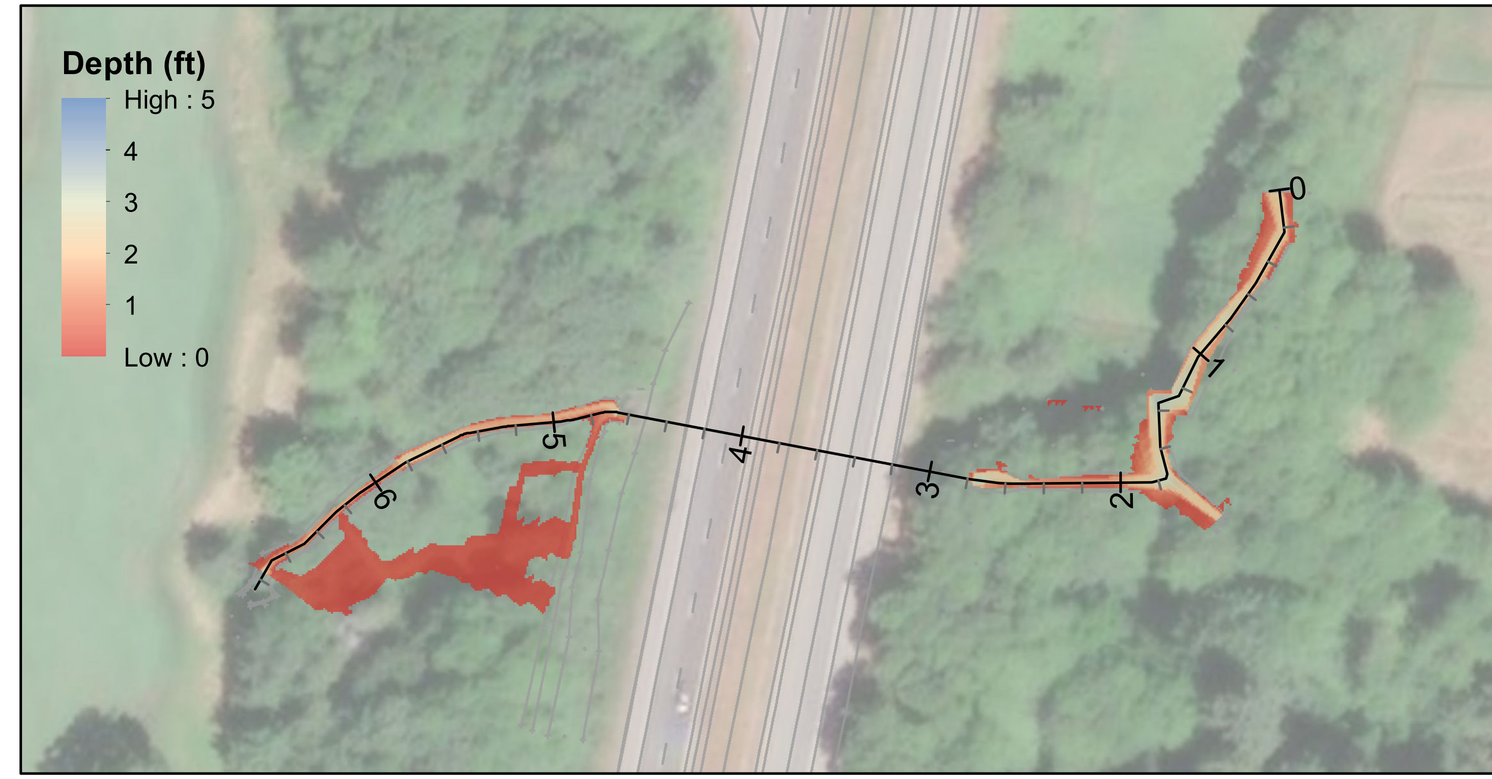

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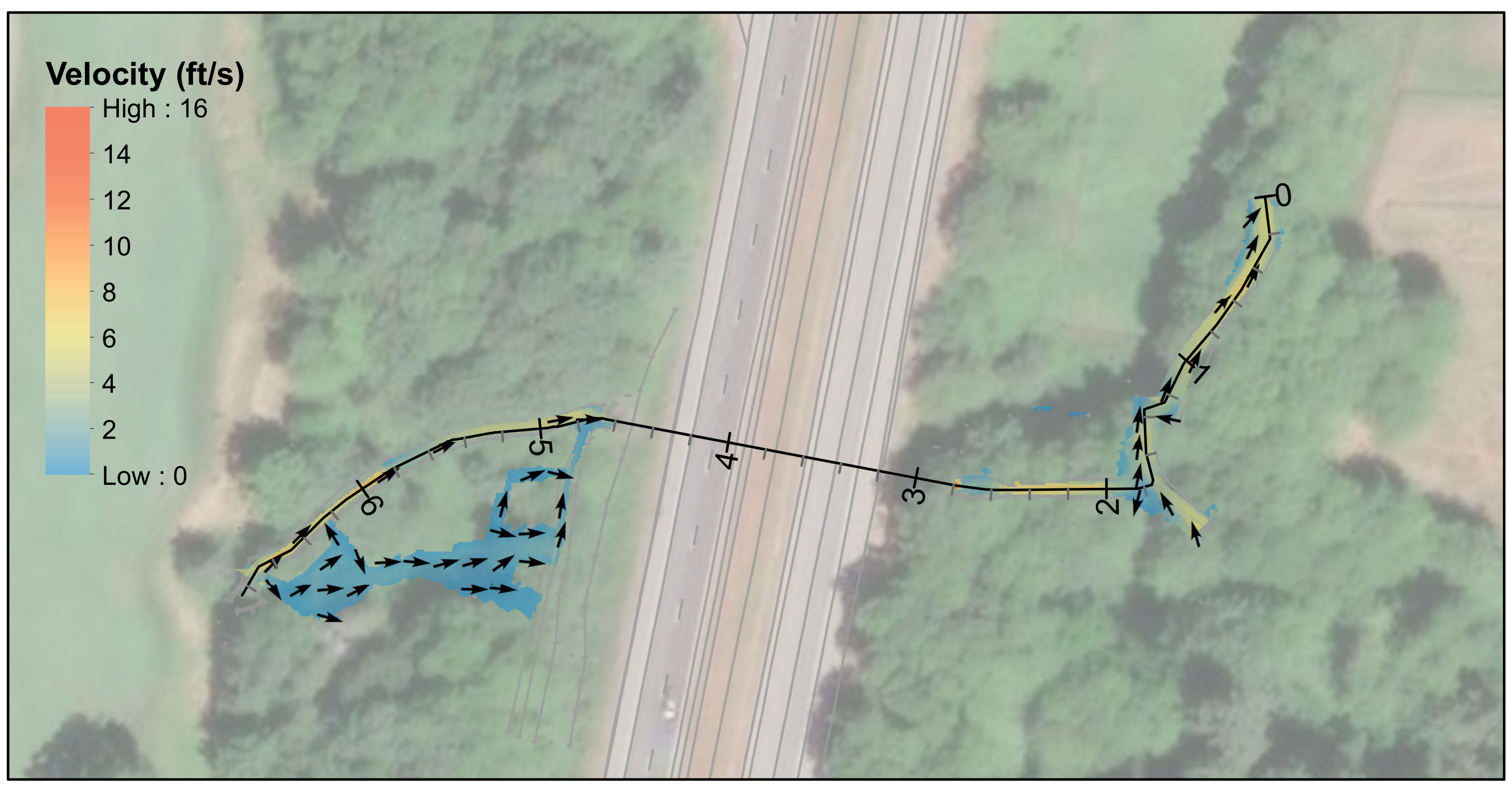

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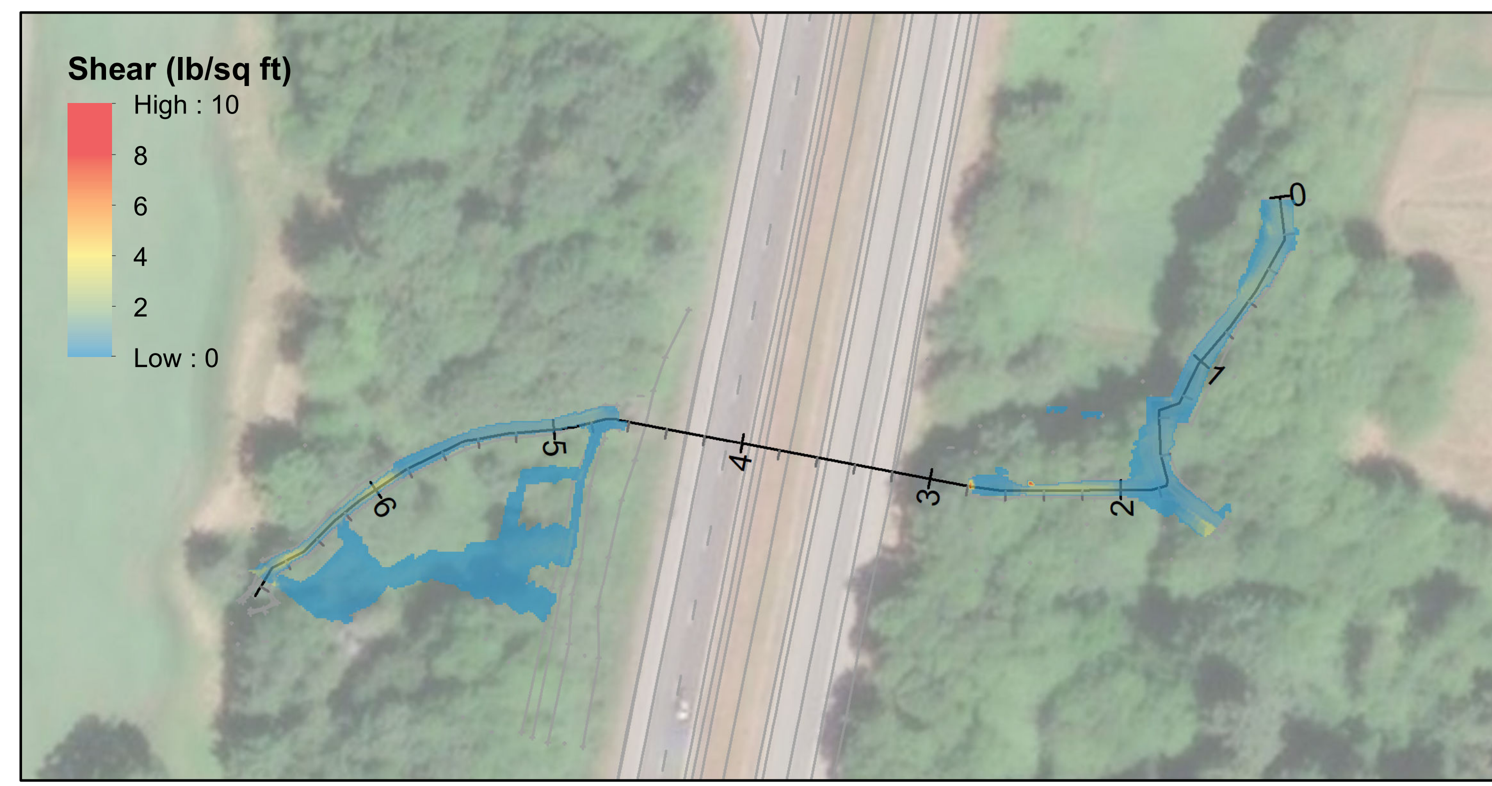

SHEAR

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0 50 100 Feet

Washington State Department of Transportation

EXISTING CONDITIONS - 50 YEAR EVENT

US 101 UNNAMED TRIBUTARY TO SKOOKUM CREEK
MP 354.01

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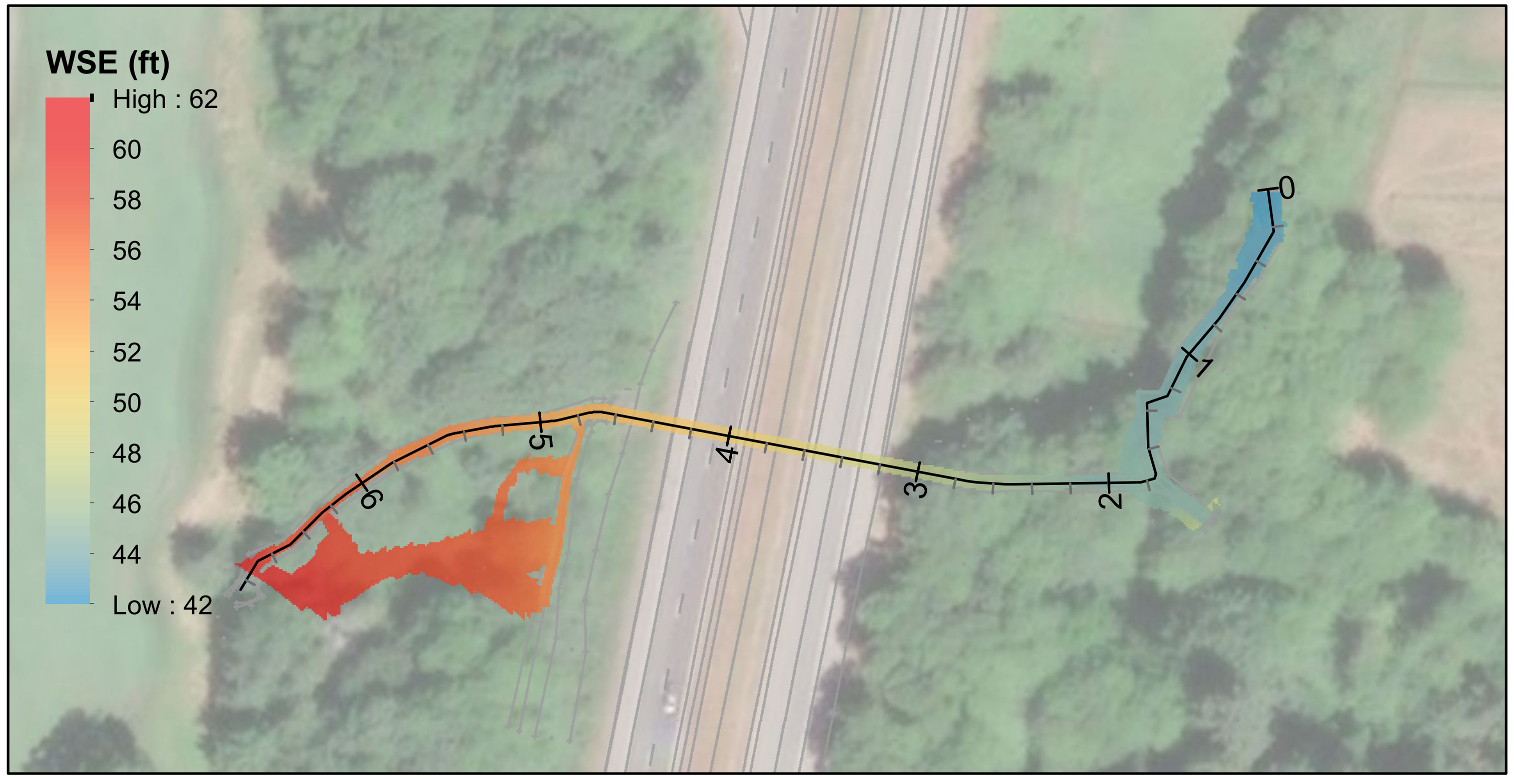
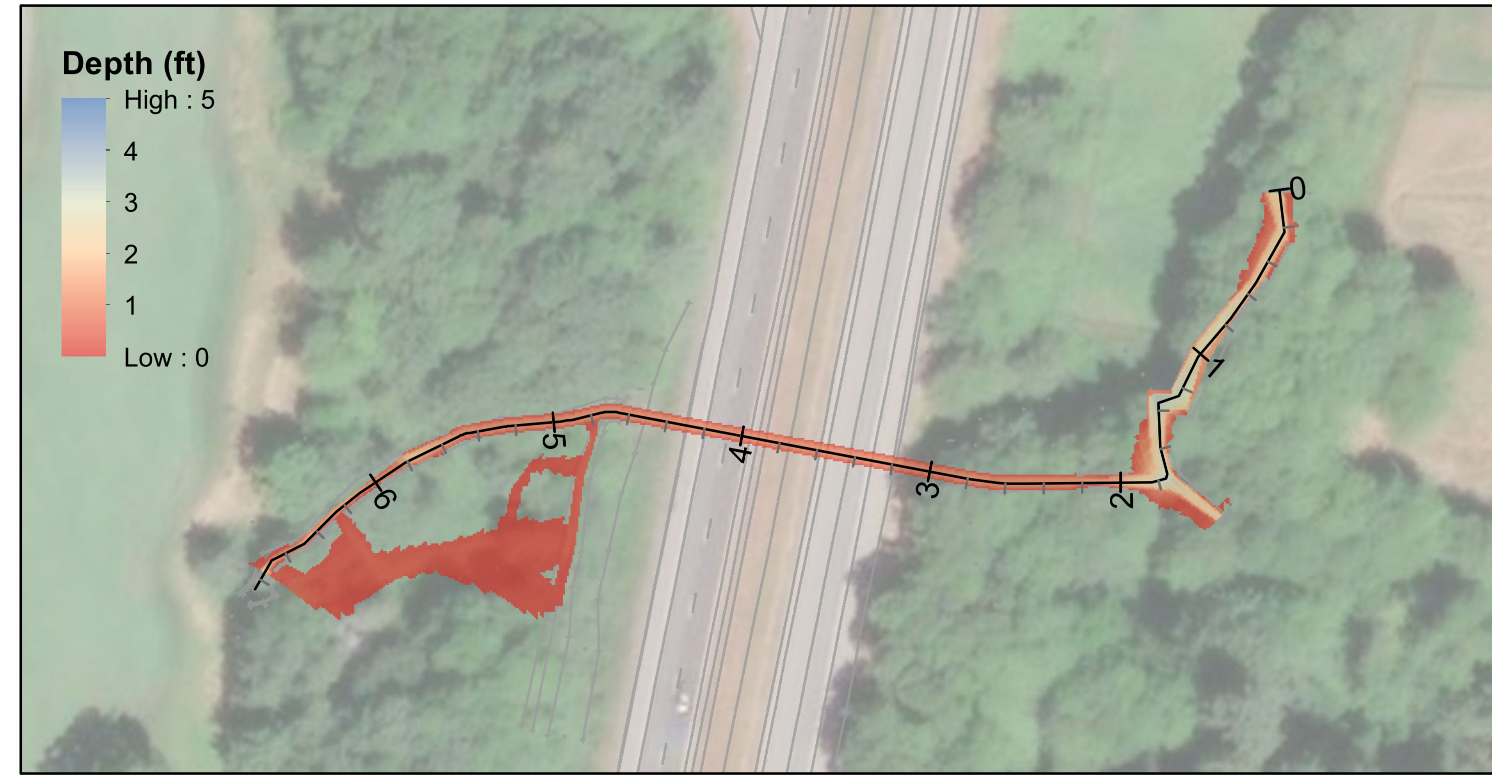


WATER SURFACE ELEVATION



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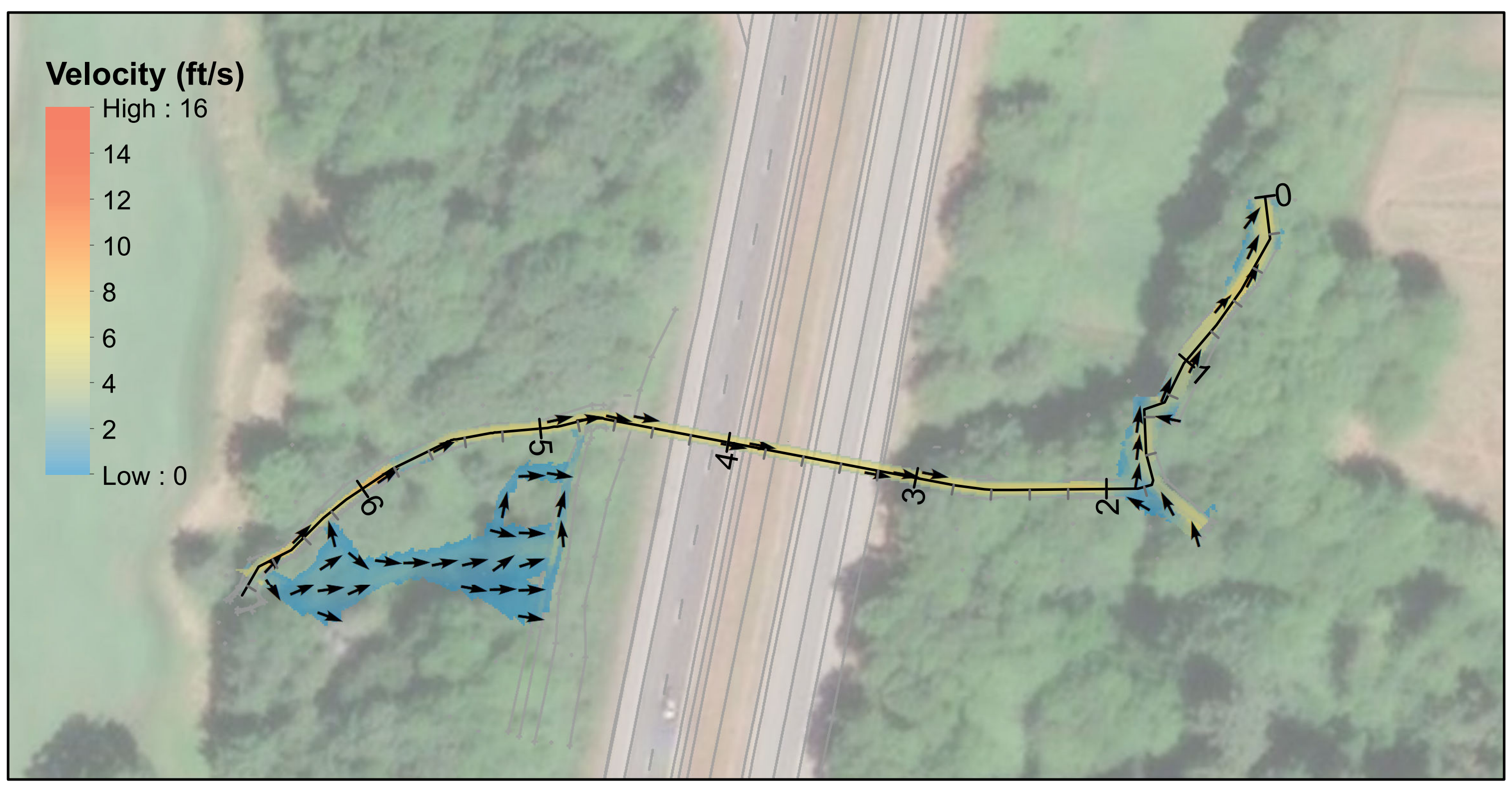

VELOCITY

SHEAR

N

0 50 100 Feet

Washington State Department of Transportation

PROPOSED CONDITIONS - 50 YEAR EVENT

US 101 UNNAMED TRIBUTARY TO SKOOKUM CREEK
MP 354.01

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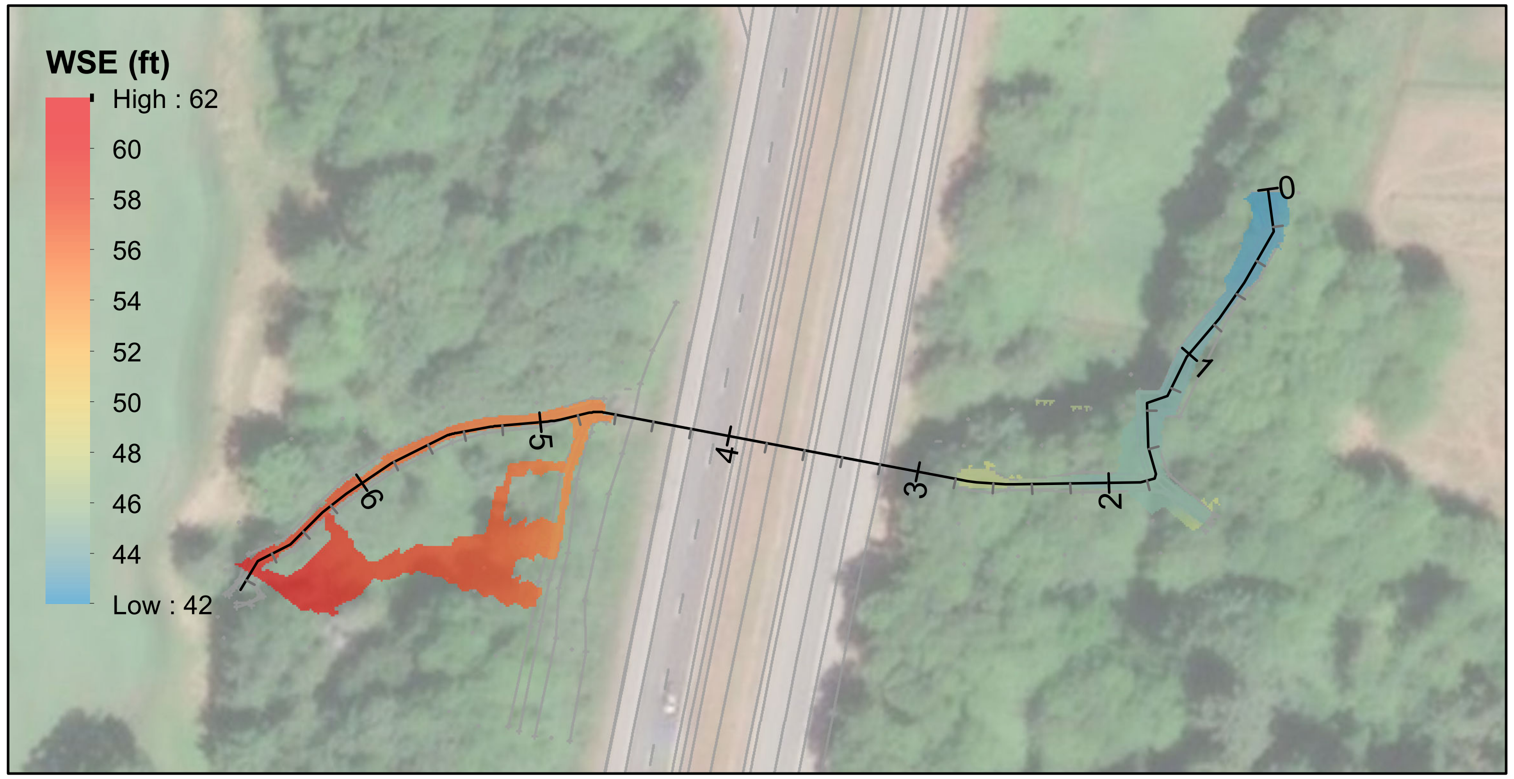
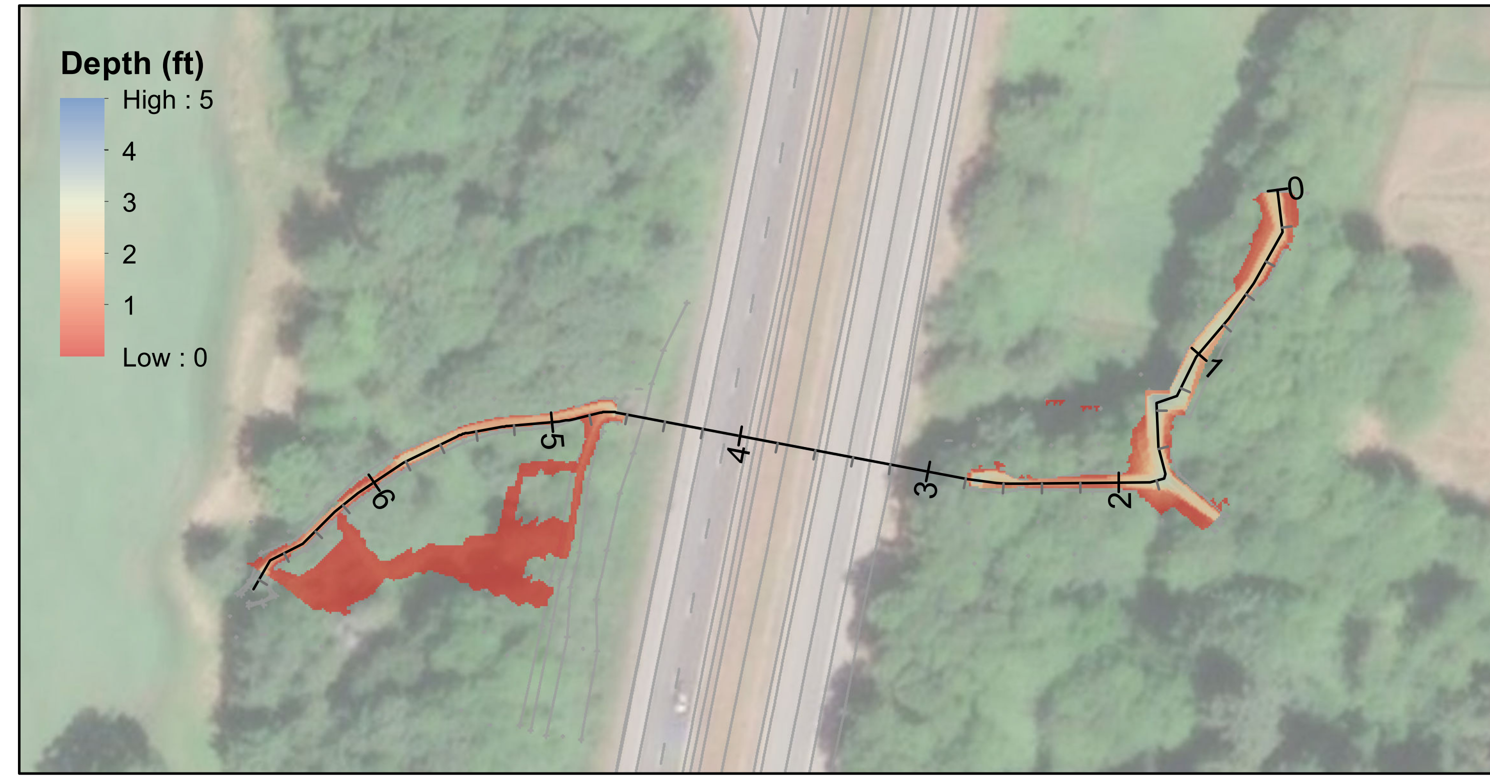
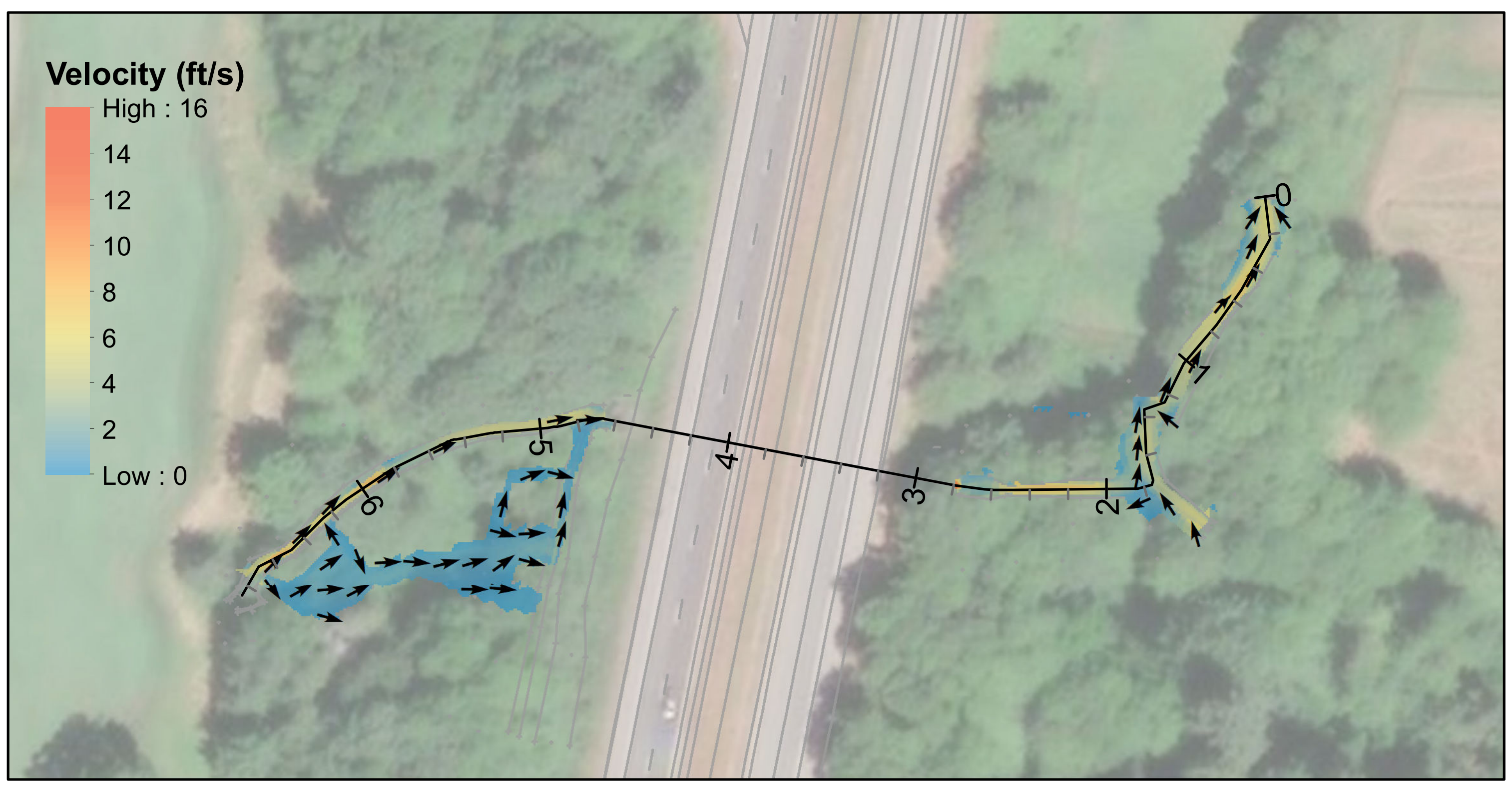
PRELIMINARY HYDARULIC DESIGN



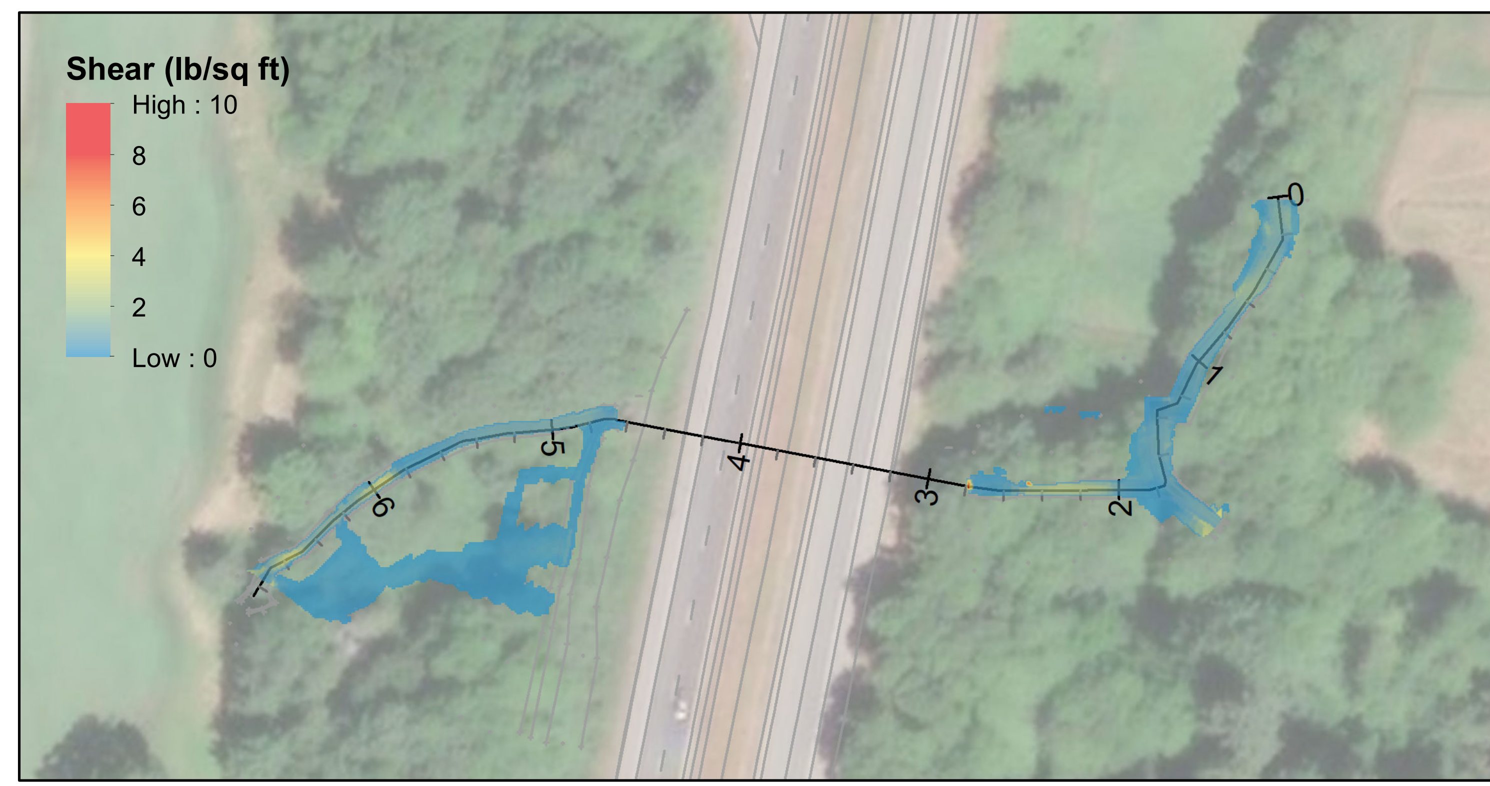
WATER SURFACE ELEVATION



DEPTH



VELOCITY



SHEAR

N

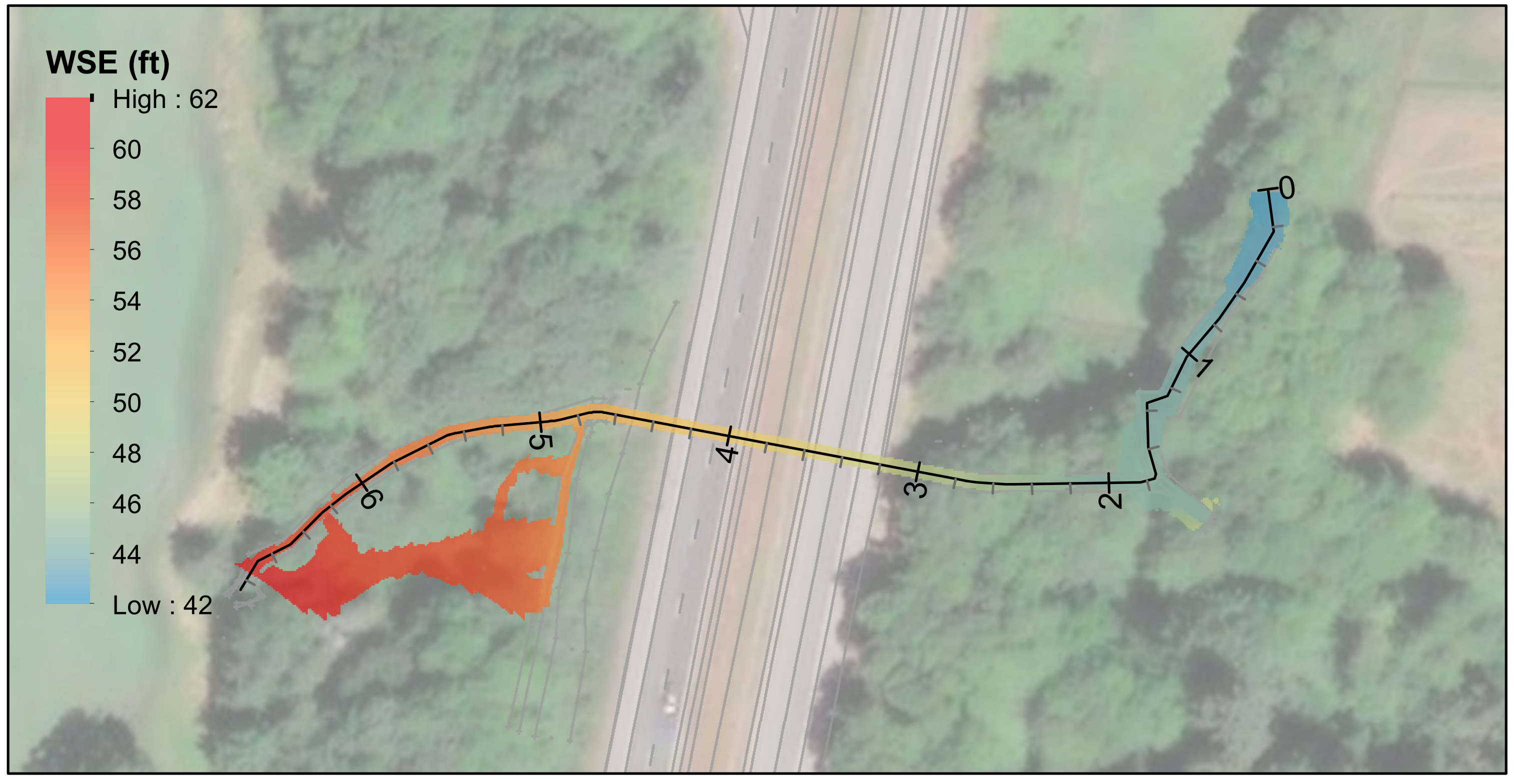
0 50 100 Feet

HDR

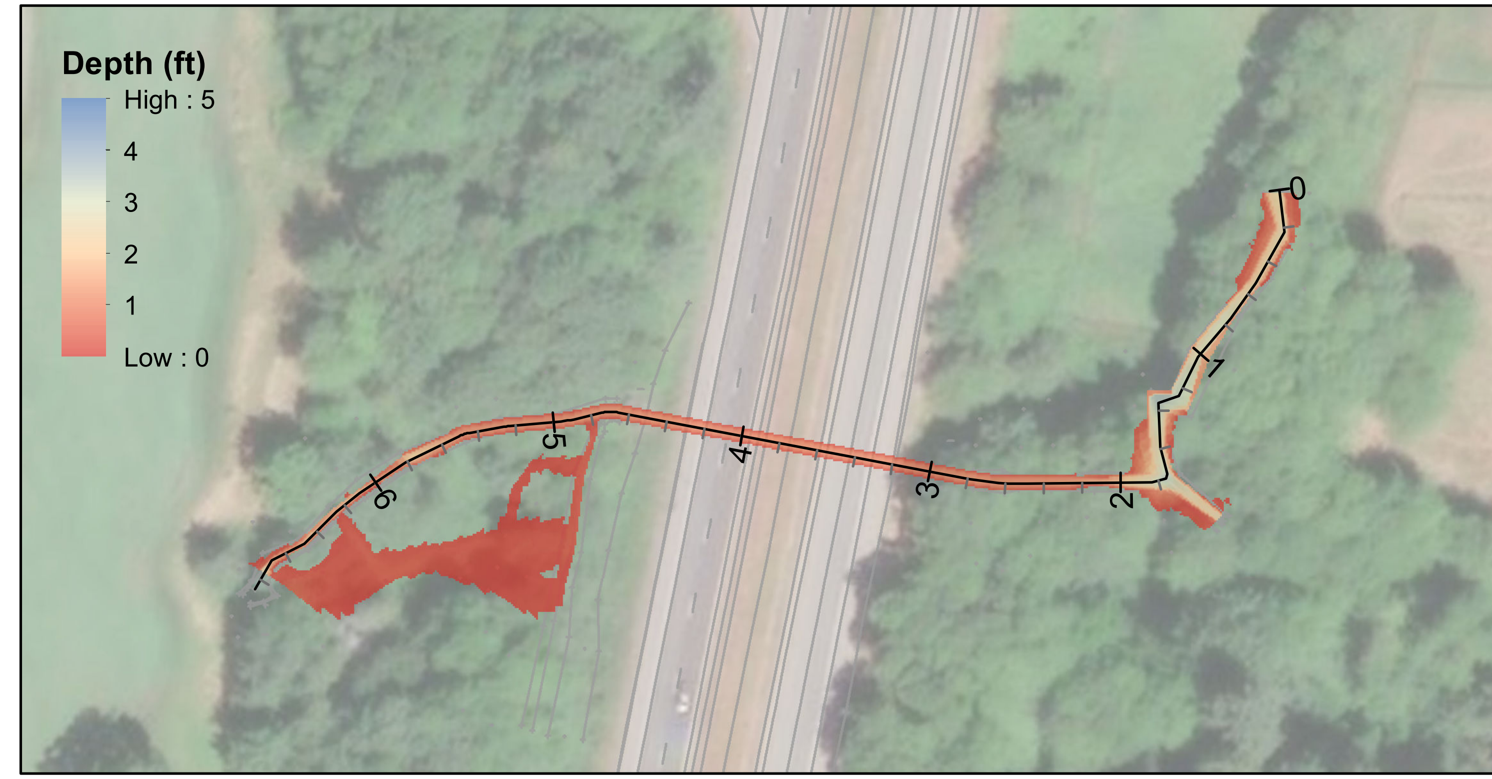
Washington State Department of Transportation

EXISTING CONDITIONS - 100 YEAR EVENT

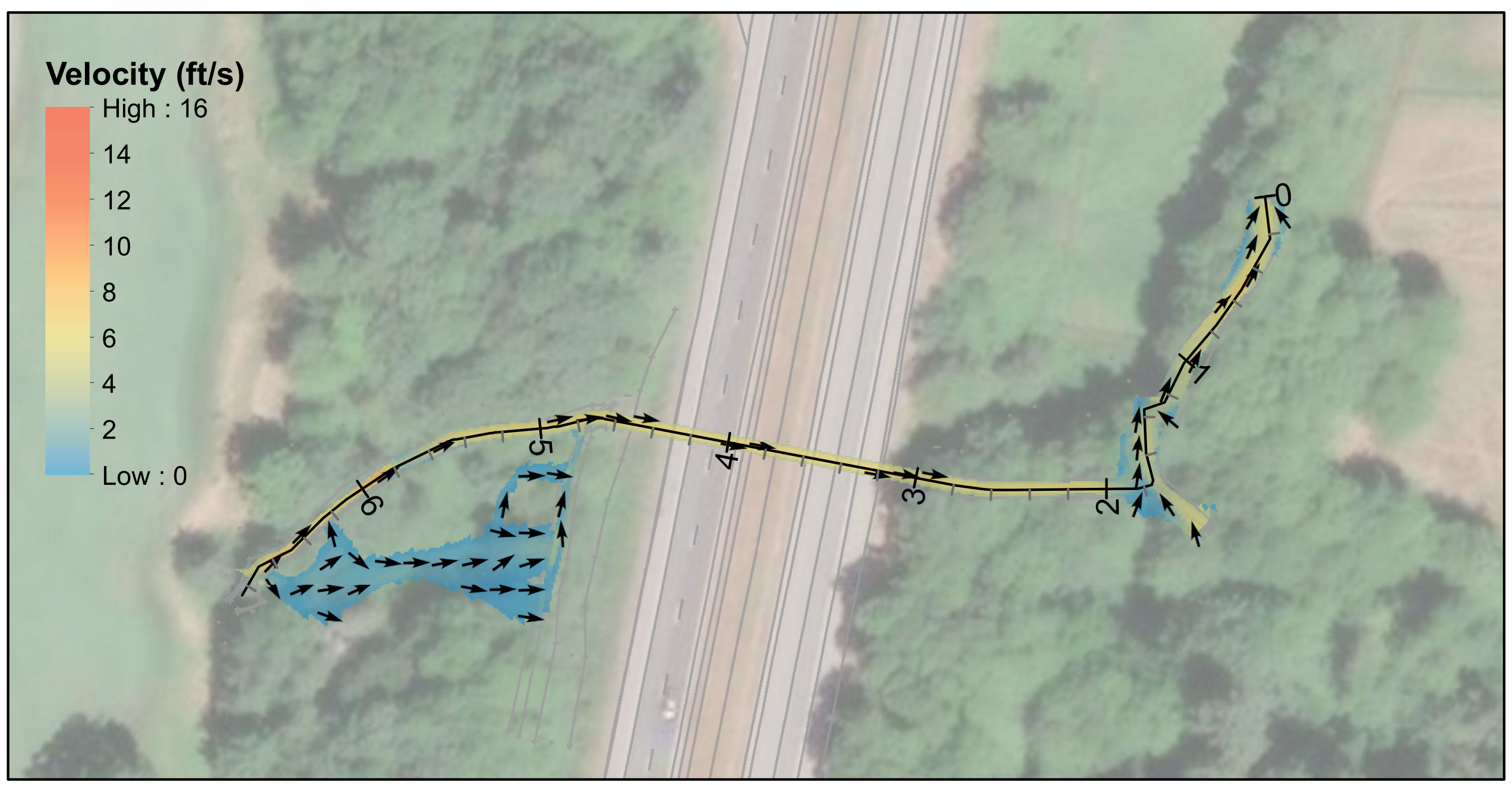
US 101 UNNAMED TRIBUTARY TO SKOOKUM CREEK
MP 354.01



WATER SURFACE ELEVATION



DEPTH



VELOCITY

SHEAR

N

0 50 100 Feet

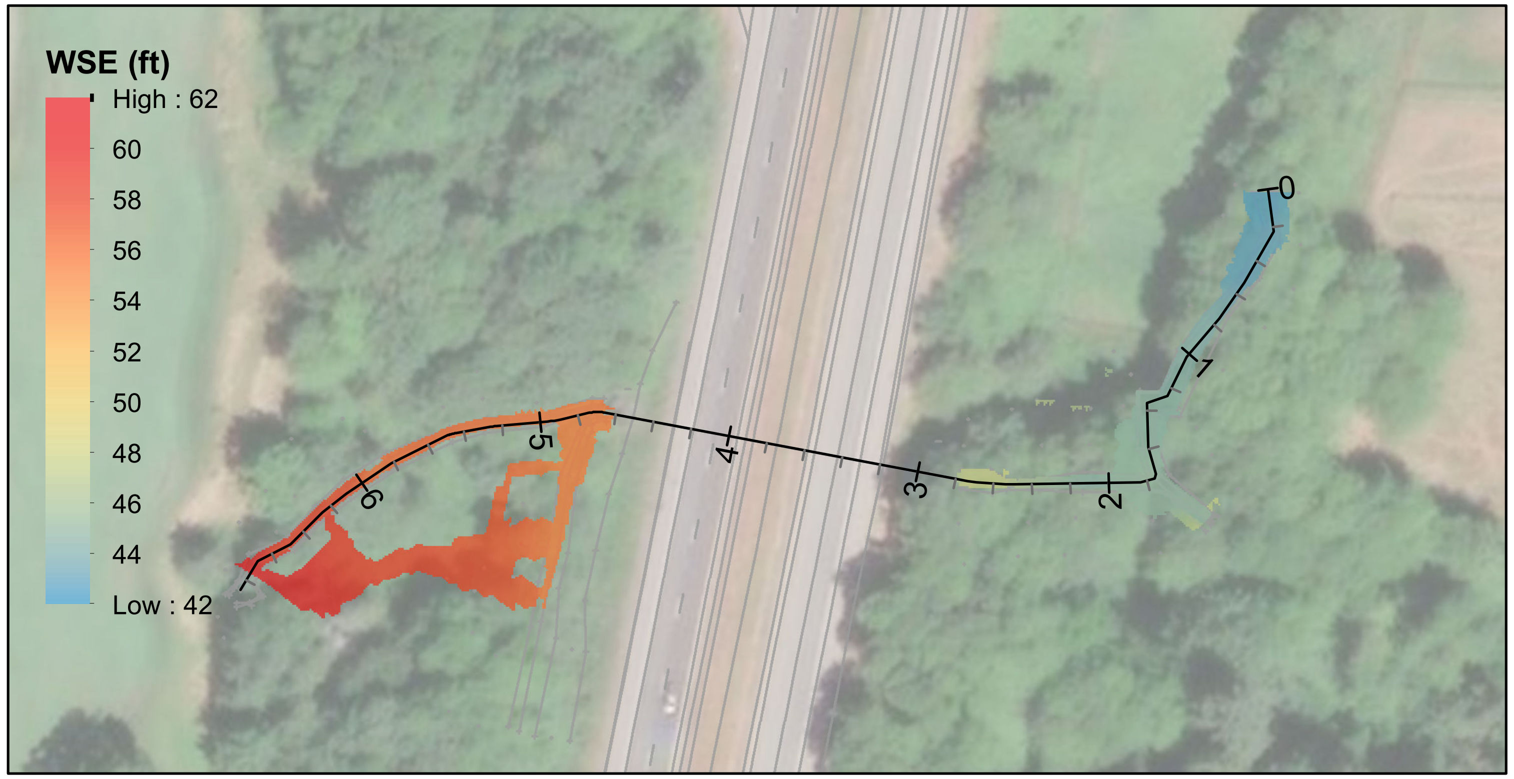
Washington State Department of Transportation

PROPOSED CONDITIONS - 100 YEAR EVENT

US 101 UNNAMED TRIBUTARY TO SKOOKUM CREEK
MP 354.01

PATH: S:\US101_MP354\RESULTS\OUTPUT FIGURES\PROPOSED_100YR FINAL.MXD - USER: DMINNER - DATE: 10/1/2019

PRELIMINARY HYDARULIC DESIGN



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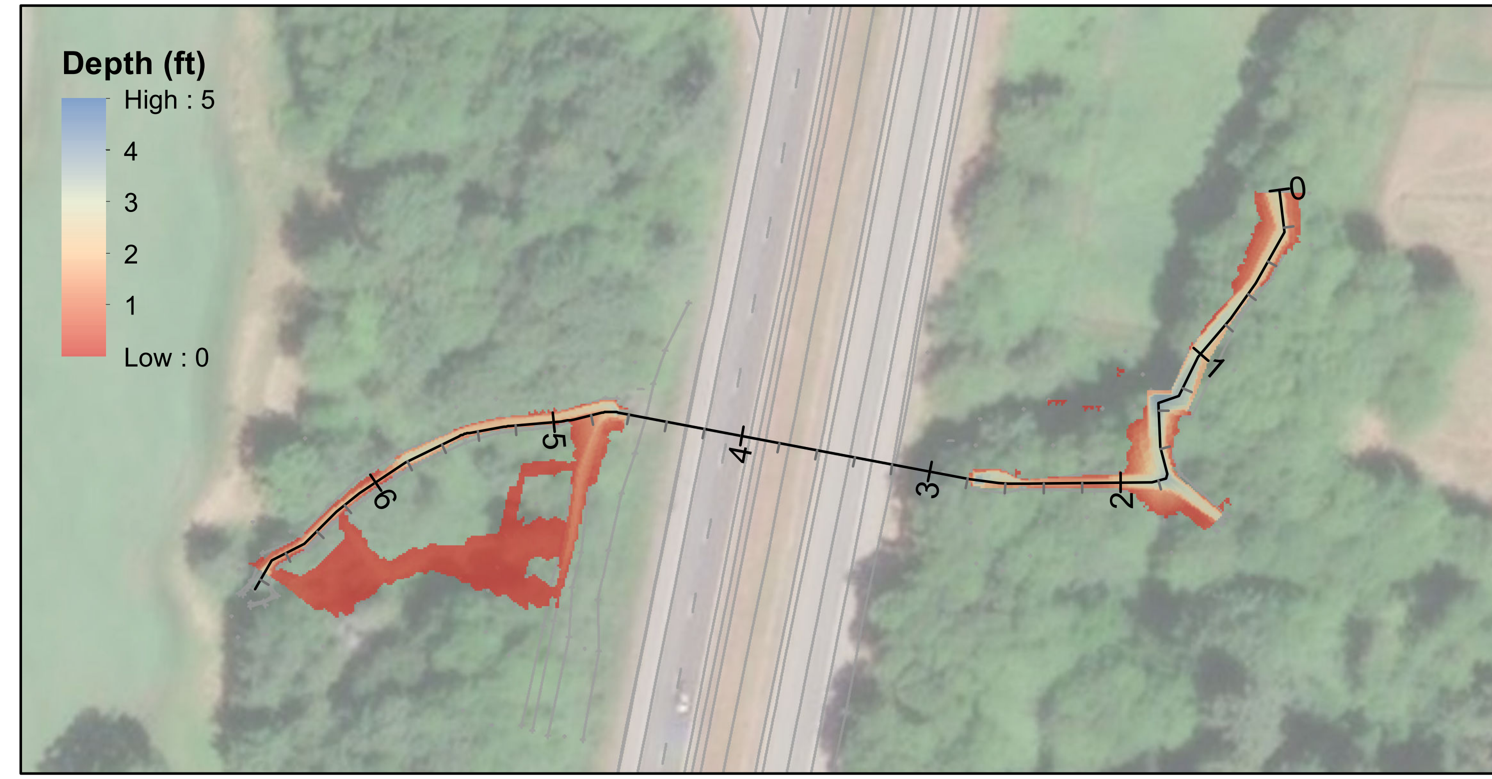

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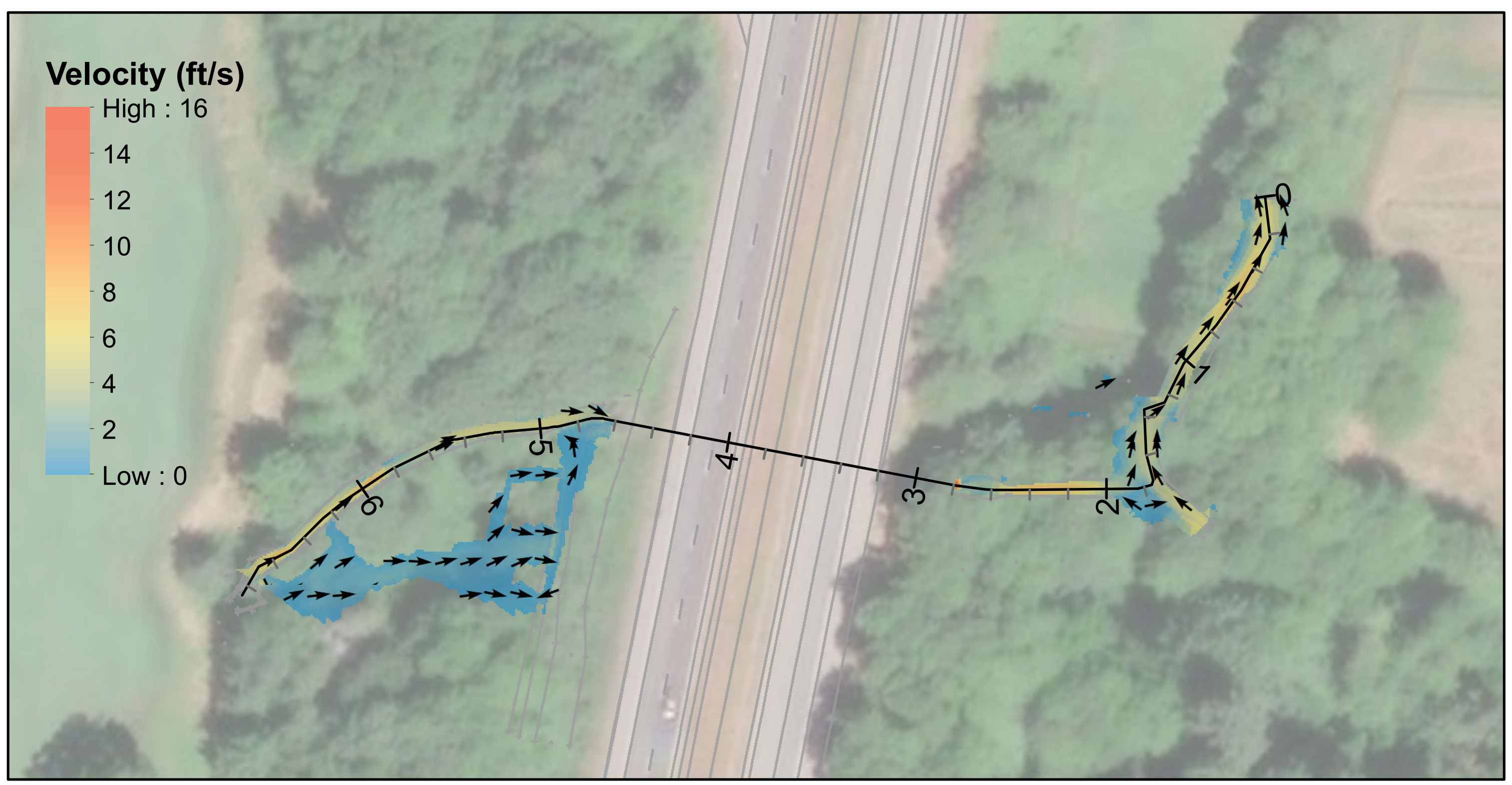
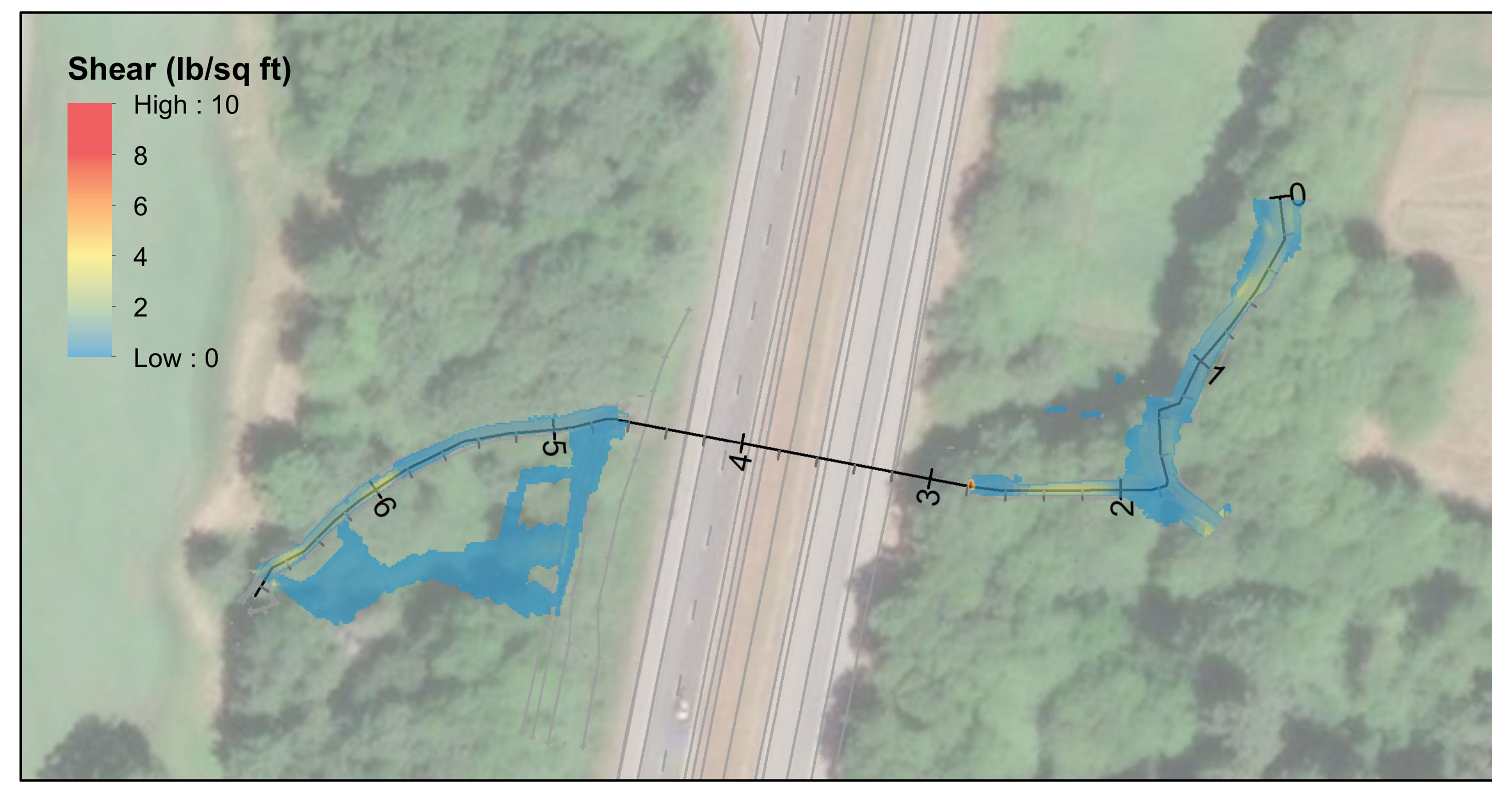


VELOCITY



SHEAR

N

0 50 100 Feet

HDR

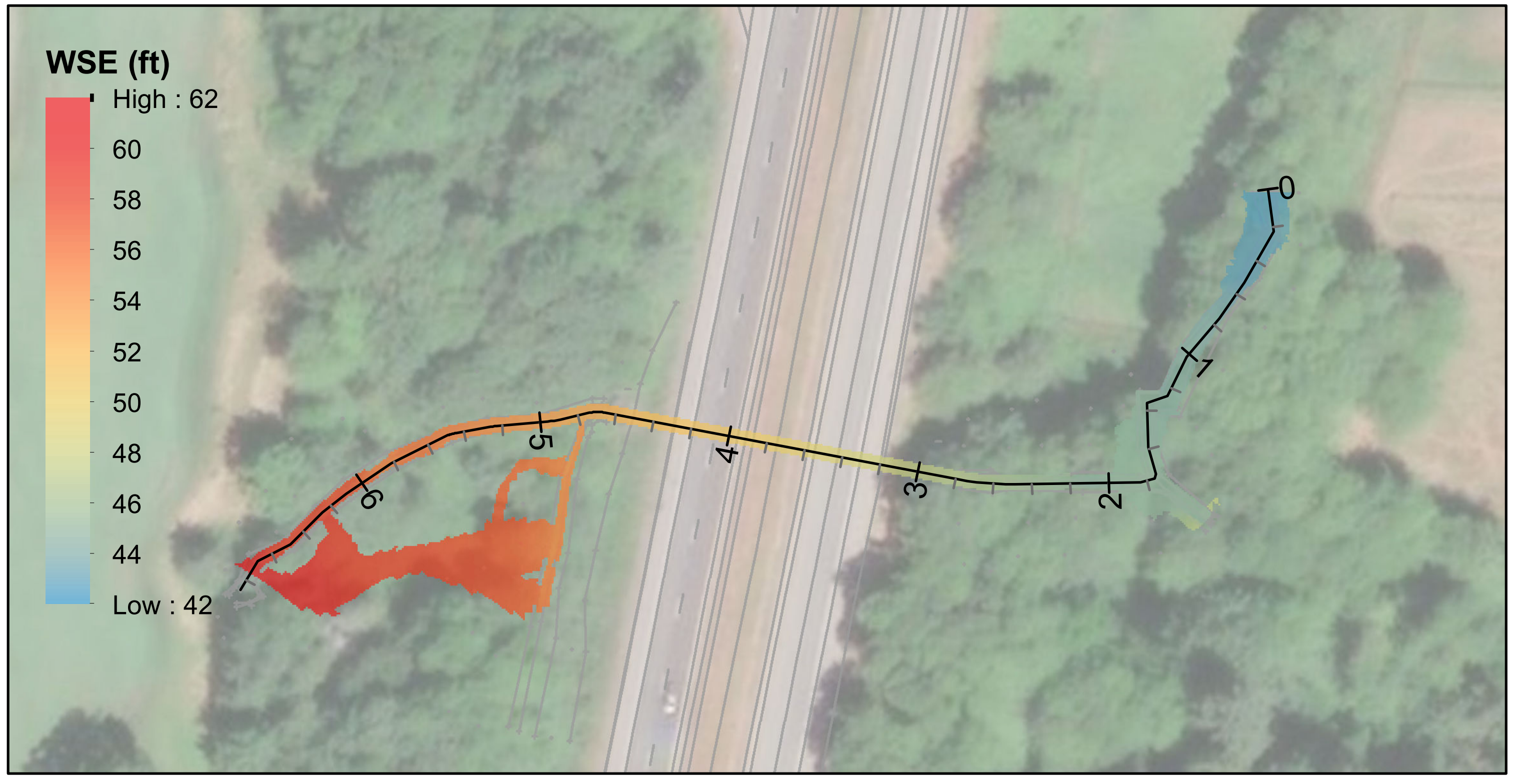
Washington State Department of Transportation

EXISTING CONDITIONS - 500 YEAR EVENT

US 101 UNNAMED TRIBUTARY TO SKOOKUM CREEK
MP 354.01

PATH: S:\US101_MP354\RESULTS\OUTPUT FIGURES\EXISTING_500YR FINAL.MXD - USER: DMINNER - DATE: 10/1/2019

PRELIMINARY HYDARULIC DESIGN



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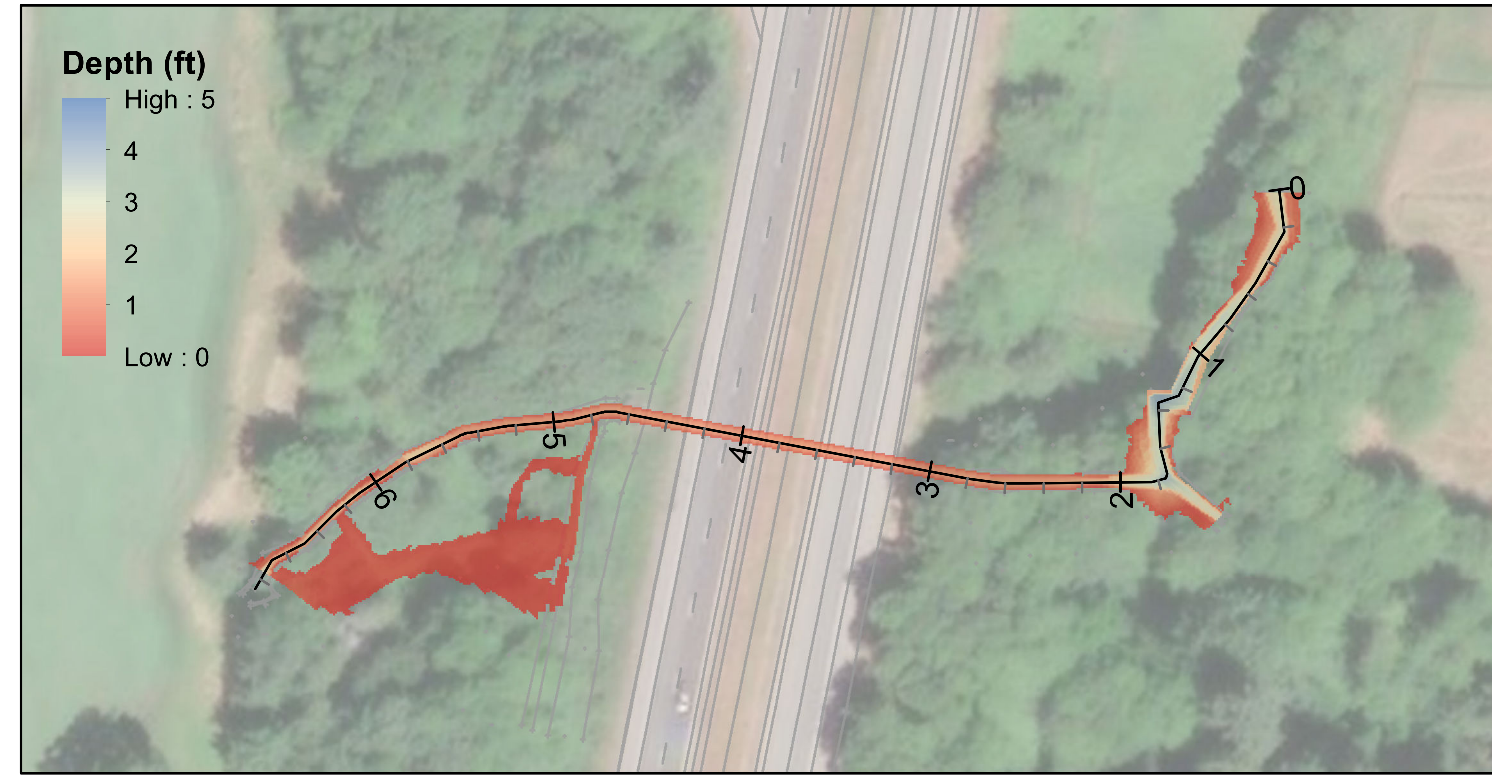
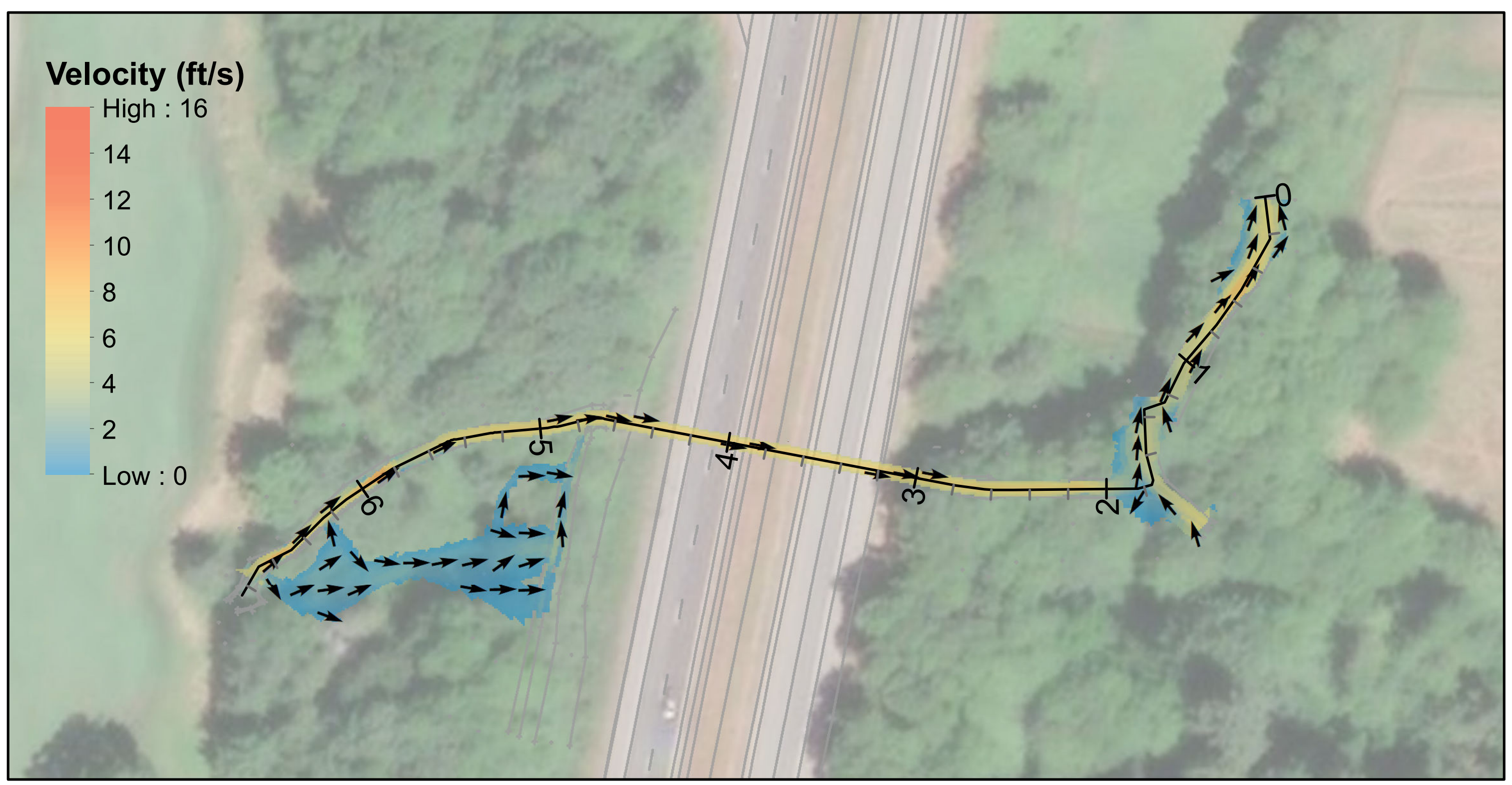


DEPTH



VELOCITY

SHEAR

N

0 50 100 Feet

HDR

Washington State Department of Transportation

PROPOSED CONDITIONS - 500 YEAR EVENT

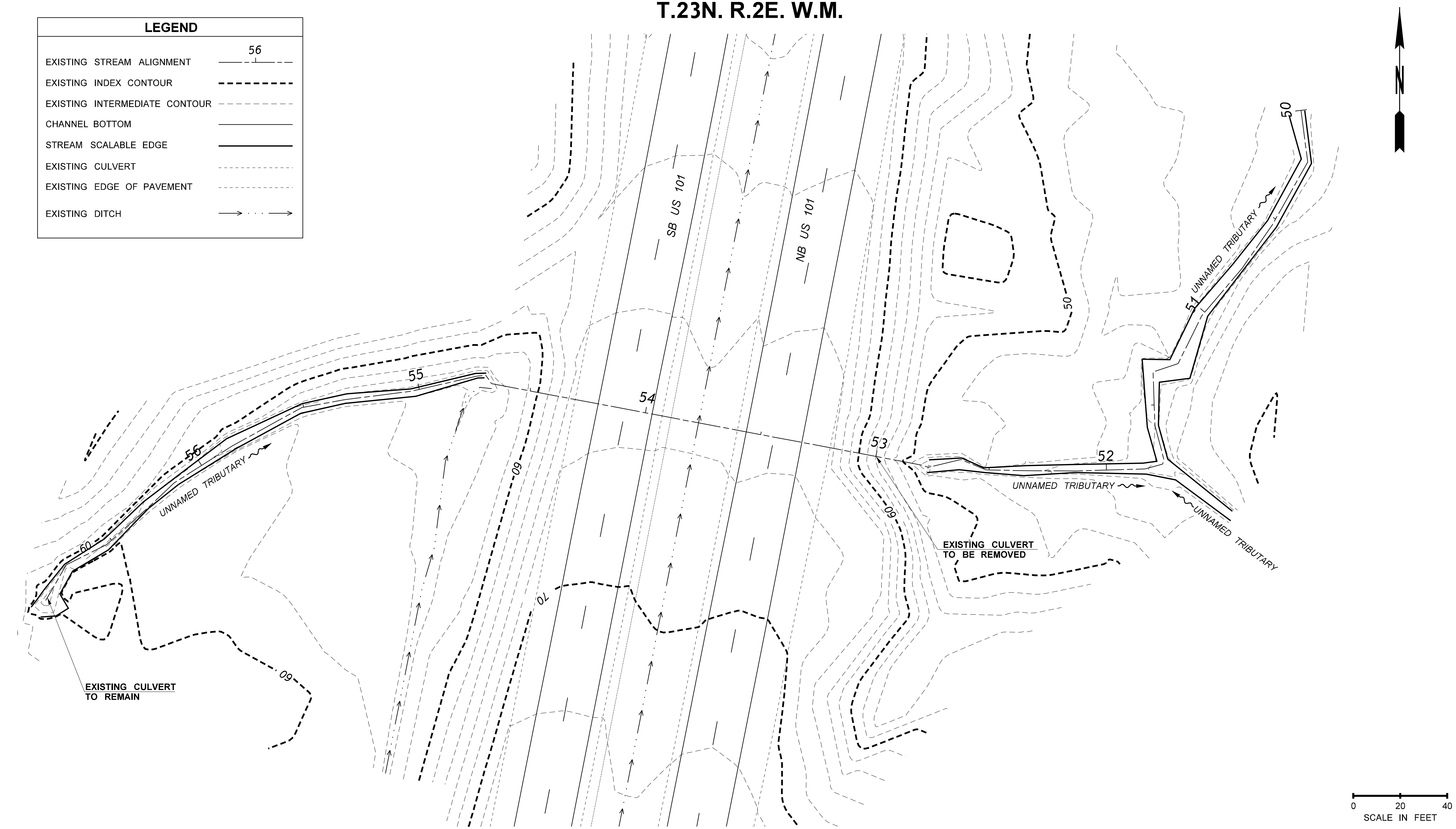
US 101 UNNAMED TRIBUTARY TO SKOOKUM CREEK
MP 354.01

PATH: S:\US101_MP354\RESULTS\OUTPUT FIGURES\PROPOSED_500YR FINAL.MXD - USER: DMINNER - DATE: 10/1/2019

PRELIMINARY HYDARULIC DESIGN

Appendix B – Stream Plan Sheets, Profile, Details

T.23N. R.2E. W.M.



PRELIMINARY - NOT FOR CONSTRUCTION

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DESIGNED BY	S. BEVAN			
ENTERED BY	C. WILCOX			
CHECKED BY	J. HEILMAN			
PROJ. ENGR.	J. METTLER			
REGIONAL ADM.	J. WYNANDS	REVISION	DATE	BY

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	
JOB NUMBER XXXXX		
CONTRACT NO.		LOCATION NO. XL5950

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State Department of Transportation

HDR

US 101
MP 354.01
SKOOKUM CREEK TRIBUTARY

EXISTING STREAM PLAN

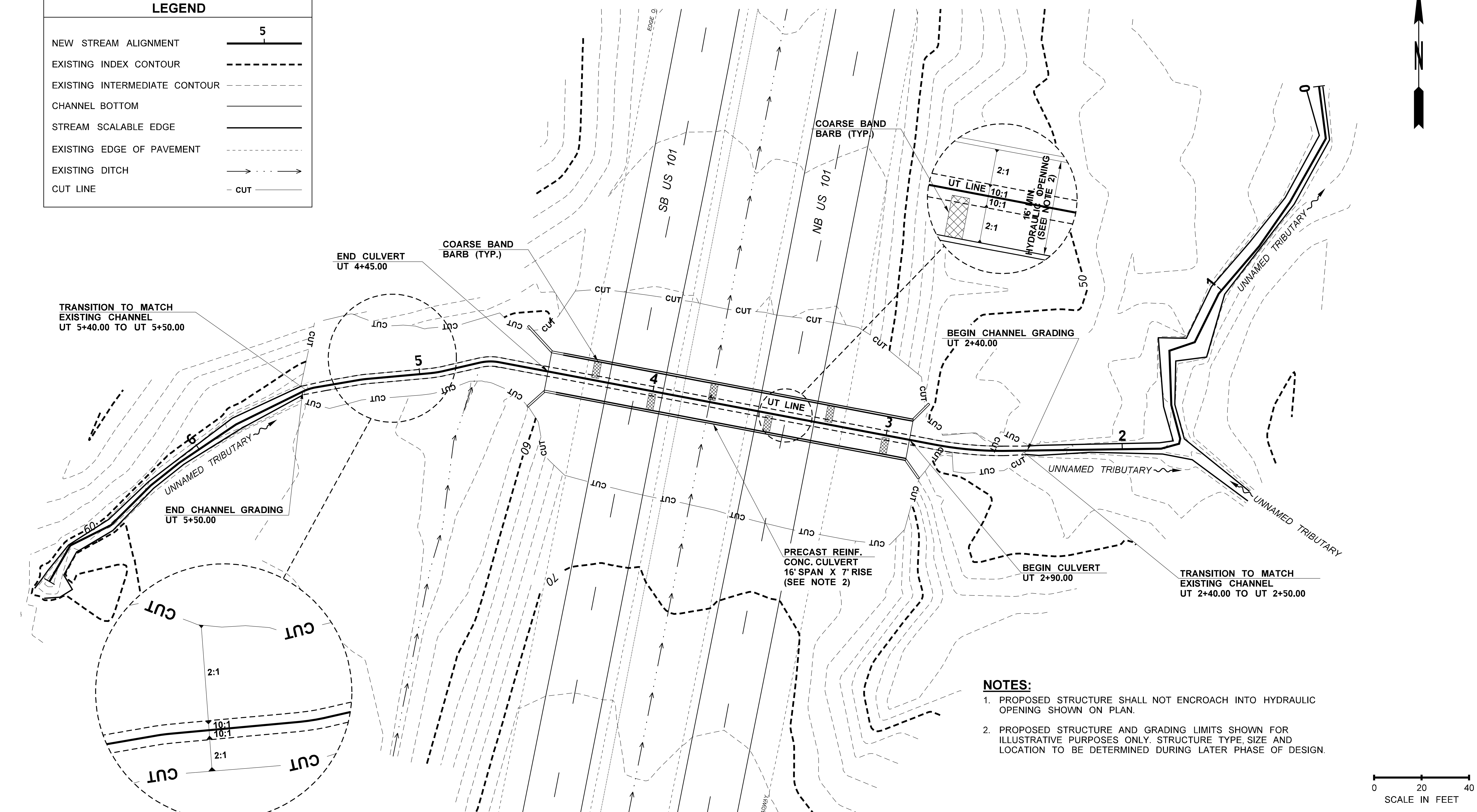
PLAN REF NO CE1

SHEET 1 OF 4 SHEETS

T.19N. R.3W. W.M.

LEGEND

NEW STREAM ALIGNMENT	5
EXISTING INDEX CONTOUR	
EXISTING INTERMEDIATE CONTOUR	
CHANNEL BOTTOM	
STREAM SCALABLE EDGE	
EXISTING EDGE OF PAVEMENT	
EXISTING DITCH	
CUT LINE	CUT



NOTES:

1. PROPOSED STRUCTURE SHALL NOT ENCROACH INTO HYDRAULIC OPENING SHOWN ON PLAN.
2. PROPOSED STRUCTURE AND GRADING LIMITS SHOWN FOR ILLUSTRATIVE PURPOSES ONLY. STRUCTURE TYPE, SIZE AND LOCATION TO BE DETERMINED DURING LATER PHASE OF DESIGN.

PRELIMINARY - NOT FOR CONSTRUCTION

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DESIGNED BY	S. BEVAN
ENTERED BY	C. WILCOX
CHECKED BY	J. HEILMAN
PROJ. ENGR.	J. METTLER
REGIONAL ADM.	J. WYNANDS

REVISION	DATE	BY

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	
JOB NUMBER XXXXX		
CONTRACT NO.		LOCATION NO. XL5950

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State Department of Transportation

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US 101
MP 354.01
SKOOKUM CREEK TRIBUTARY

STREAM PLAN

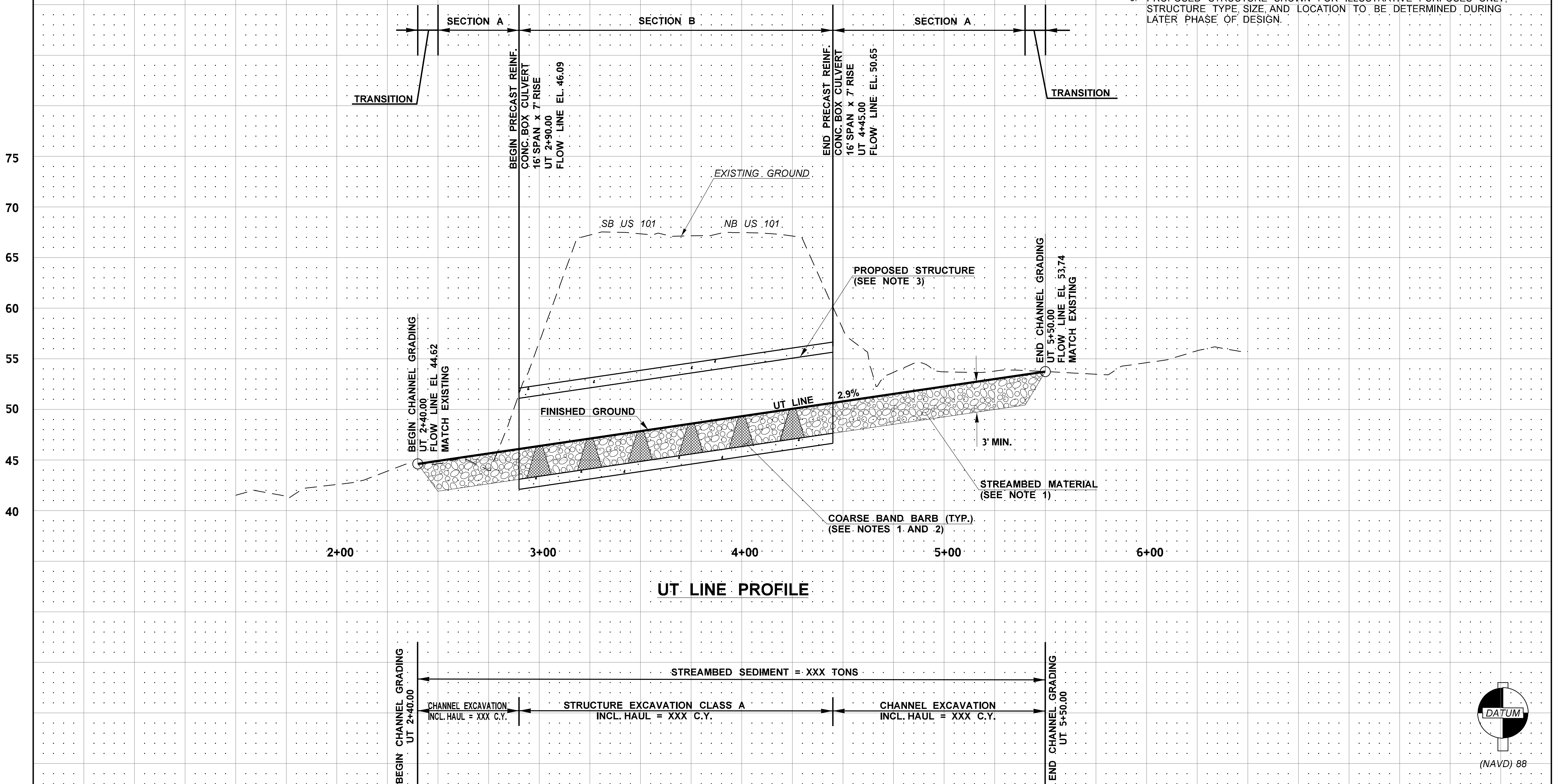
PLAN REF NO CR1

SHEET 2 OF 4 SHEETS

pw:\\HQOLYMAPPPW03P.WSDOT.LOC:WSDOT\Documents_HQ\Fish Passage\ORproj\101\354.01_TribToSkookumCr1\Hydraulics_CAD_Sheets\StreamPlanProfDetails\XL5950_PS_CR_001

NOTES:

1. SEE SPECIAL PROVISIONS "AGGREGATES FOR STREAMS, RIVERS, AND WATERBODIES FOR STREAMBED MATERIALS.
2. SEE SHEET CD1 FOR STREAM SECTIONS.
3. PROPOSED STRUCTURE SHOWN FOR ILLUSTRATIVE PURPOSES ONLY, STRUCTURE TYPE, SIZE, AND LOCATION TO BE DETERMINED DURING LATER PHASE OF DESIGN.



PRELIMINARY - NOT FOR CONSTRUCTION

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CHECKED BY	J. HEILMAN			
PROJ. ENGR.	J. METTLER			
REGIONAL ADM.	J. WYNANDS	REVISION	DATE	BY

REGION NO. 10	STATE WASH	FED.AID PROJ.NO.
JOB NUMBER XXXXX		
CONTRACT NO.		LOCATION NO. XL5950

P.E. STAMP BOX — DATE

P.E. STAMP BOX — DATE

Washington State Department of Transportation

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US 101
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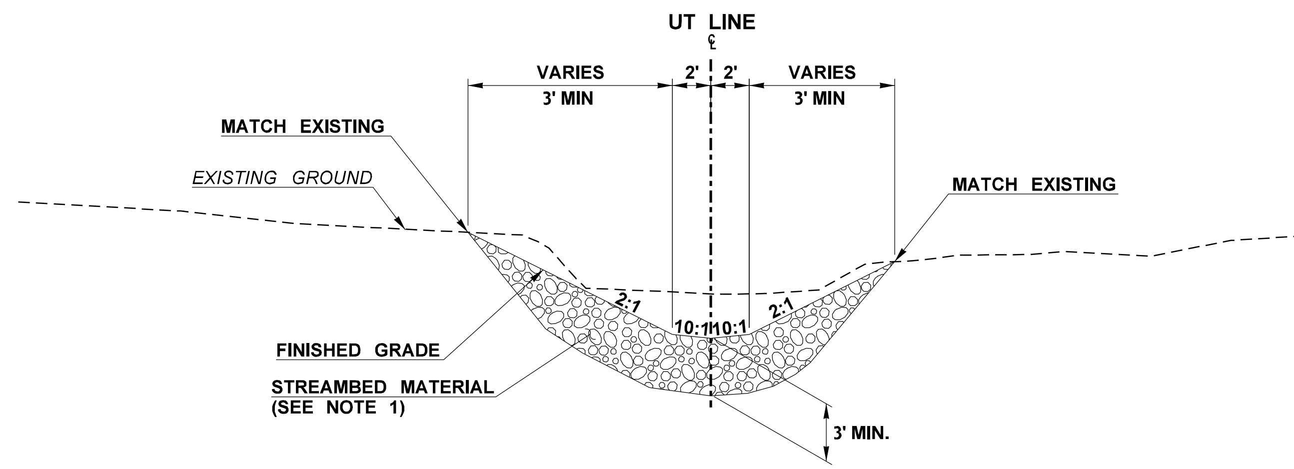
SKOOKUM CREEK TRIBUTARY

STREAM PROFILE

PLAN REF. NO. CP1

SHEET 3 OF 4 SHEETS



SECTION A

STATION
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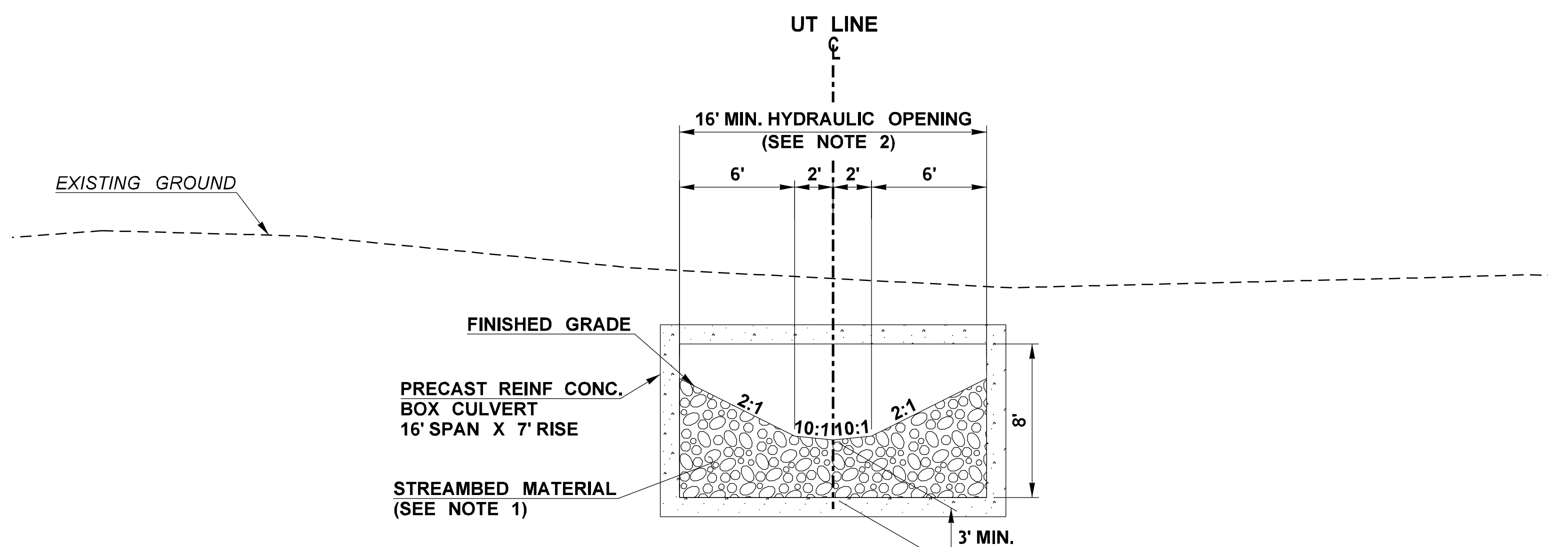
UT 4+45.00 TO 5+40.00



SECTION B

STATION
UT 2+90.00 TO 4+45.00

NOTES:

1. SEE SPECIAL PROVISIONS "AGGREGATE FOR STREAMS, RIVERS, AND WATERBODIES" FOR STREAMBED MATERIAL.
2. PROPOSED STRUCTURE SHALL NOT ENCROACH INTO MINIMUM OPENING SHOWN ON PLAN.

PRELIMINARY - NOT FOR CONSTRUCTION

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DESIGNED BY	S. BEVAN
ENTERED BY	C. WILCOX
CHECKED BY	J. HEILMAN
PROJ. ENGR.	J. METTLER
REGIONAL ADM.	J. WYNANDS

REVISION	DATE	BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO.

JOB NUMBER XXXXX

CONTRACT NO. | LOCATION NO. XL5950

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State Department of Transportation

HDR

US 101
MP 354.01
SKOOKUM CREEK TRIBUTARY

STREAM DETAILS

PLAN REF NO CD1

SHEET 4 OF 4 SHEETS

pw:\\HQOLYMAPPW03P.WSDOT.LOC:WSDOT\Documents_HQ\Fish Passage\ORproj\101\354.01_TribToSkookumCr1\Hydraulics_CAD_Sheets\StreamPlanProfDetails\XL5950_DE_CD_001

Appendix C – WDFW Future Projections for Climate-Adapted Culvert Design Printout

Future Projections for Climate-Adapted Culvert Design

Project Name: 997158

Stream Name:

Drainage Area: 34 ac

Projected mean percent change in bankfull flow:

2040s: 13.9%

2080s: 20.5%

Projected mean percent change in bankfull width:

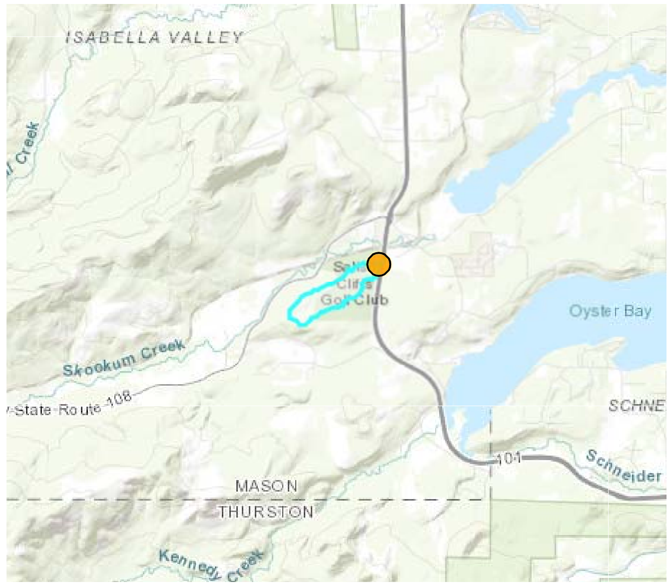
2040s: 6.7%

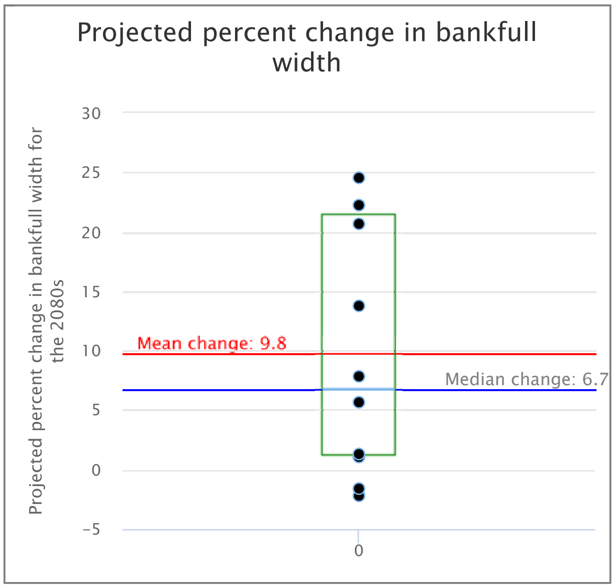
2080s: 9.8%

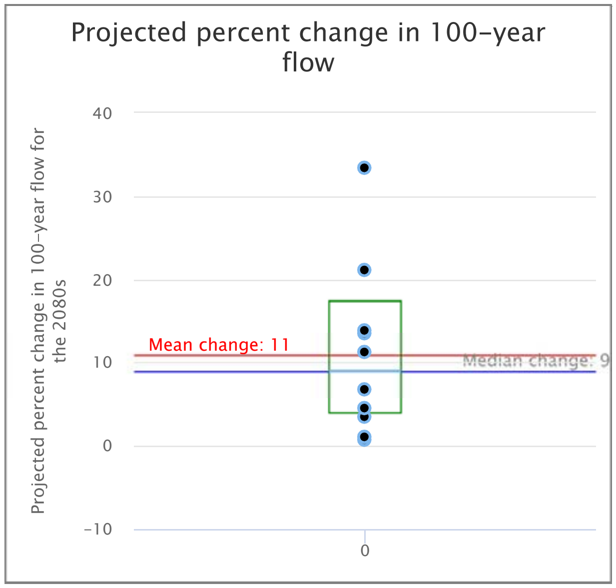
Projected mean percent change in 100-year flood:

2040s: 6.4%

2080s: 11%







Black dots are projections from 10 separate models